CARBON DIOXIDE INVENTORY FOR BRITISH COLUMBIA

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The data and technical assessments are preliminary in nature and may therefore change as research in this area continues. Those using the information are responsible for confirming its accuracy and its appropriateness to their own use.

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EXECUTIVE SUMMARY

The trapping of infrared radiation released from the earth by carbon dioxide (CO_2) and other gases, known as the greenhouse effect, has become a household term in recent years. There is general agreement among the scientific community that the concentration of CO_2 (and other greenhouse gases) is rising. There is still considerable debate, however, whether or not this is causing increased temperatures. Man's daily activities, primarily involving the combustion of fossil and biofuels, is recognized as a major contributor to increases in atmospheric CO_2 concentrations.

This study has sought to quantify anthropogenic CO_2 emissions and natural sinks in an inventory for the years 1988 and 2005. Opportunities for reducing CO_2 emissions were also studied and discussed.

The Energy, Mines and Petroleum Resources (EMPR), Forecasts and Special Projects Branch, provided most of the energy consumption estimates for 1988. These estimates were recently prepared for use in an update "Energy Supply and Requirements Forecast" report.

The EMPR primarily relies on information from Statistics Canada, especially the "Quarterly Report on Energy Supply and Demand" 57-003. Additional information is usually supplied by contact with industry. On occasion, Statistics Canada information is manipulated by EMPR to better reflect situations in B.C.

The inventory was organized into five CO_2 emission source categories according to Environment Canada's "National Inventory of Sources and Emissions of CO_2 (1987)", (Jaques, 1989). These categories were:

- Process sources
- Stationary combustion sources
- Mobile combustion sources
- Solid waste disposal
- Prescribed burning.

EMPR energy consumption statistics for B.C. in 1988 were used for the stationary and mobile combustion source categories. The only exceptions to this were in the gas utilities and railroad sectors where industry statistics were used. All other information used to complete the CO_2 emissions inventory were gathered from discussions with industry and government representatives. The favourable response received from industry and government were invaluable in making the inventory as complete and accurate as possible.

Emission factors used to convert energy consumption into CO_2 emissions were taken from Environment Canada's National CO_2 inventory (Jaques, 1989).

Release of CO_2 by soil respiration is an important source that could not be reliably estimated for this inventory. There are few data on decomposition rates for different ecosystems in different stages of stand development. Lacking such information, one alternative is to assume that in the long term CO_2 fixation and CO_2 release are more or less in equilibrium in any given ecosystem. Such an assumption, if incorrect, would not create a great error for the smaller CO_2 sinks in British Columbia (rivers, wetlands and lakes). For forests, the major CO_2 sink in the province, it would be desirable to have better estimates of CO_2 release from dead organic matter on the forest floor and in forest soils. For the present inventory, a global estimate of the ratio between net annual carbon fixation by land plants and annual carbon release from dead organic matter was simply applied to the estimate of annual carbon fixation by forests in British Columbia. By this estimate, decomposition of dead organic matter in forests annually releases about 90% as much carbon as is fixed each year by the province's forests.

An inventory of CO_2 sinks in B.C. for 1988 was prepared for forests, rivers, lakes and wetlands. Information from literature provided the basis for estimating the magnitude of these CO_2 sinks.

The CO_2 sinks in the forestry sector were derived by estimating net growth in mature and immature forests separately. The estimated annual biomass increment of stem wood and bark was multiplied by expansion factors to include carbon accumulation in sub-merchantable forests or non-merchantable parts of the tree to obtain the total net carbon accumulation in B.C.'s forests.

Carbon carried to the ocean in rivers and settling to the bottom of lakes and wetlands was assumed to represent the CO_2 sinks from these sources. These CO_2 sinks were underestimated because of insufficient data.

Annual CO_2 emissions in B.C. for 1988 and 2005 are reported by source sector in Figure S-1. The CO_2 estimates from this inventory, which relied heavily on data from the EMPR for stationary and mobile combustion source estimates compared well given differences in the base data, to Environment Canada's inventory (Jaques, 1989) and an inventory which used Energy, Mines and Resources (EMR) data instead of the EMPR data. The major differences between the inventories are in the industrial sector and in estimates for solid waste disposal and miscellaneous sources.

The top five annual CO_2 emissions by fuel type are reported in Figures S-2 and S-3 for 1988 and 2005, respectively. These five fuels account for about 85% of the CO_2 emissions from fuel combustion in both 1988 and 2005. Natural gas will become the largest fuel source in 2005, up from third in 1988. These five fuels contribute 68% of total CO_2 emissions in 1988 and 70% of total CO_2 emissions in 2005.

Most of the forecasts in energy requirements for 2005 for the stationary and mobile combustion categories were taken from EMPR's, "B.C. Energy Supply and Requirements Forecast, 1984-2005" report. Exceptions to this were in the gas utilities, power generation, fuel wood, road and rail sectors. These were forecast using growth factors supplied by

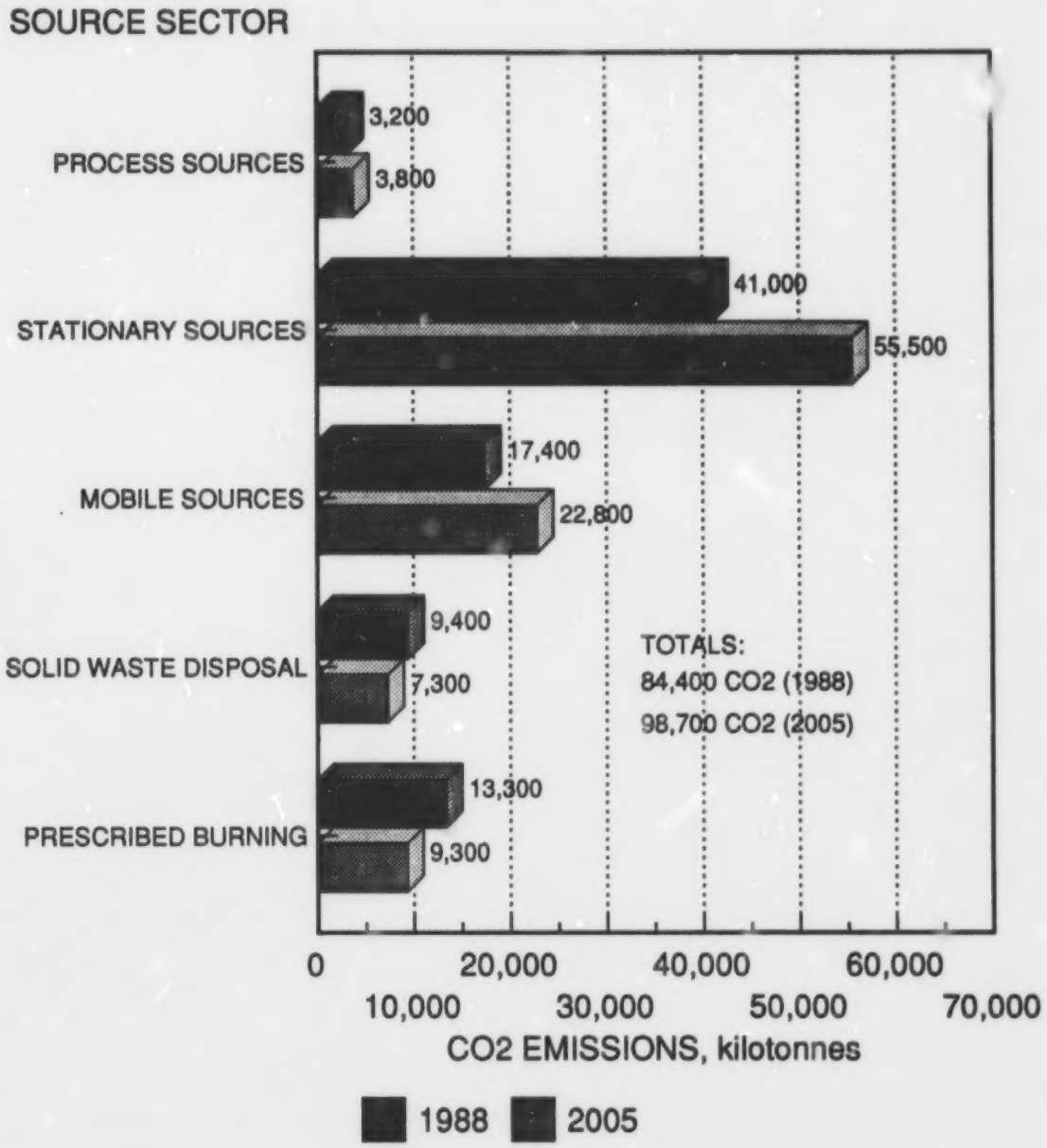


FIGURE S-1 COMPARISON OF 1988 & 2005 CO2 EMISSIONS BY MAJOR SOURCE SECTORS IN BC

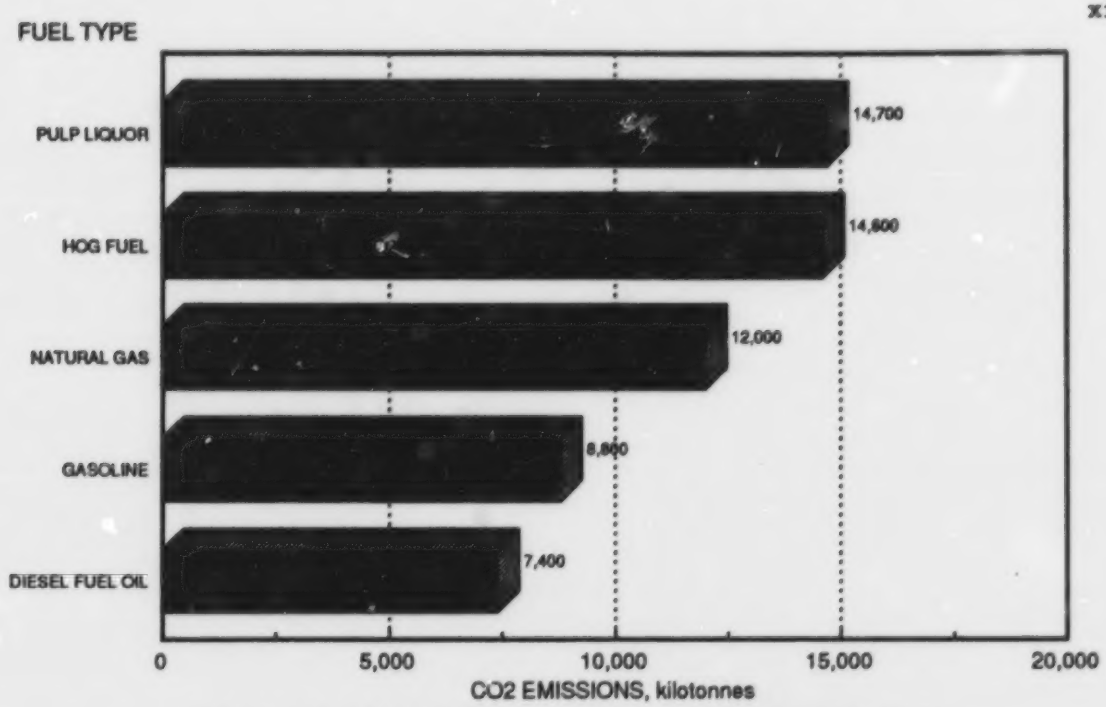


FIGURE S-2 CO2 EMISSIONS BY FUEL TYPE IN BC (1988)

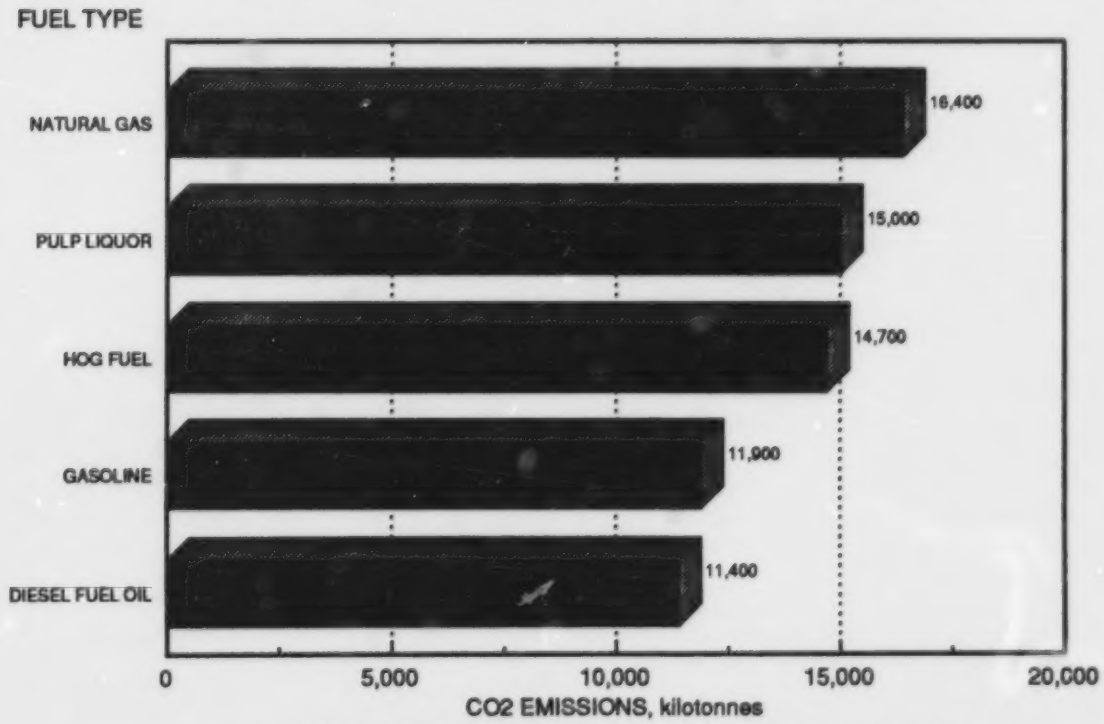


FIGURE S-3 CO2 EMISSIONS BY FUEL TYPE IN BC (2005)

Environment Canada (Sheffield, 1990). B.C. Hydro supplied energy requirements for thermal power projects expected to be in place in 2005. All other forecasts were supplied by industry and government contacts.

One could hypothesize that higher CO_2 concentrations and warmer temperatures by 2005 would stimulate increases in carbon accumulation. However, decomposition rates would increase too, partially offsetting growth increases. No quantitative forecast for CO_2 uptake in 2005 was possible because of a lack of data.

Annual CO_2 emissions in B.C. for 2005 are forecast to increase by 17% over 1988 levels. Projected decreases in CO_2 emissions from wood waste incineration and prescribed burning offset increases in CO_2 emissions from other sectors.

The top five annual CO_2 emissions for 1988 and 2005 are reported in Figures S-4 and S-5 by source sector. The five largest sources contributed 70% of total CO_2 emissions in 1988 and 63% of total CO_2 emissions in 2005.

There are a variety of opportunities for reducing the net emissions of CO_2 to the atmosphere. On a global scale, the prospect of decreasing atmospheric CO_2 through intensive forest management and afforestation is not encouraging. It is apparent that the amount of carbon that can be captured by forests is so small, relative to the total amount of CO_2 in the atmosphere, that potential reduction programs need to focus more on emissions than on sinks.

In order to meet an ambitious goal of reducing CO_2 emissions to 80% of the 1988 level, as suggested at the Toronto Conference on Climate, it is essential to first understand the nature of the greenhouse effect and the host of cause-effect relationships involved. Educating the public and setting an example is the first step policymakers should take. Society must learn to substantially change its lifestyle, not only to reduce CO_2 emissions, but also to reduce emissions and discharges of all other pollutants.

Policies which encourage energy and natural resource conservation are essential.

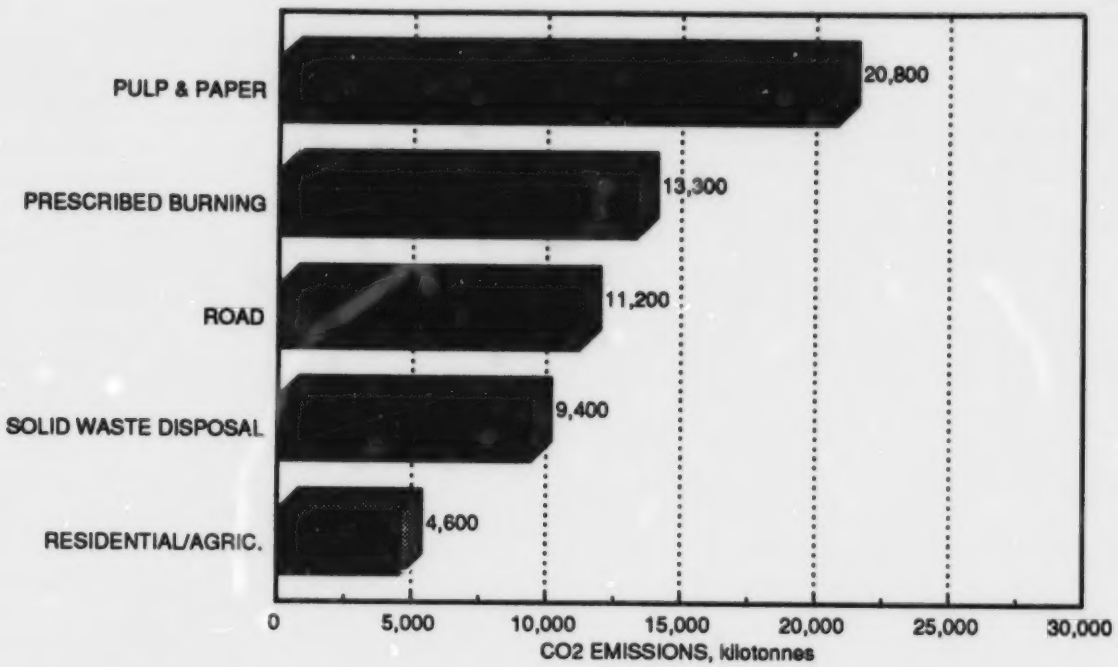


FIGURE S-4 THE TOP FIVE CO2 EMISSION SOURCES IN BC (1988)

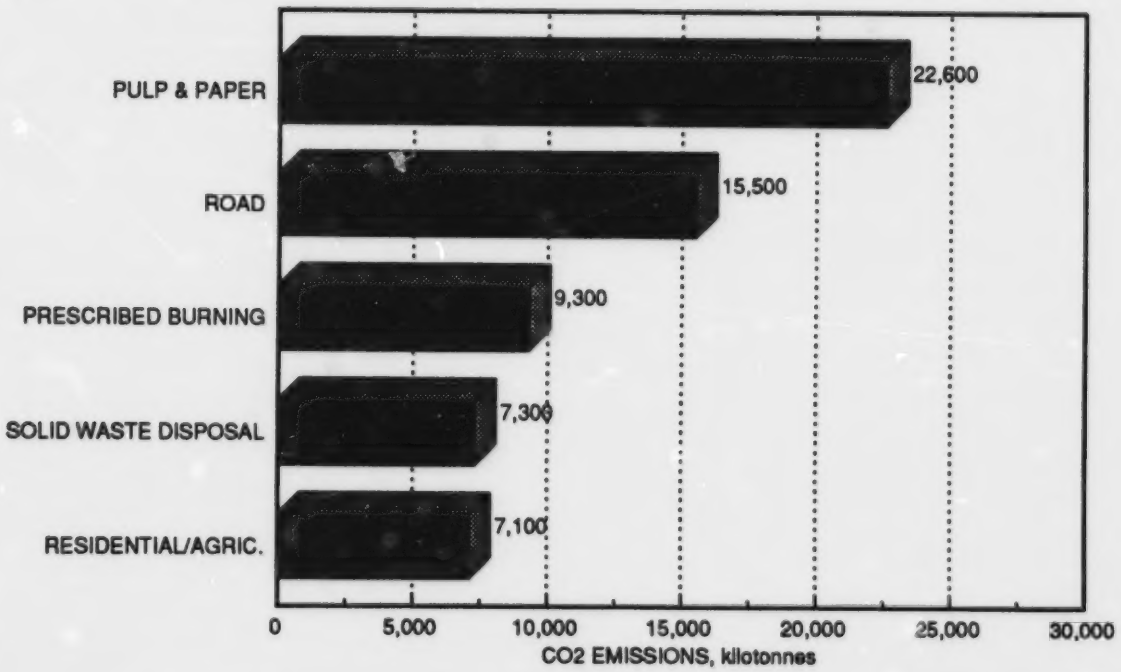


FIGURE S-5 THE TOP FIVE CO2 EMISSION SOURCES IN BC (2005)

I. INTRODUCTION

A. Background

The greenhouse effect has become a household term in recent years. Although the mechanism is different, like glass in a greenhouse, carbon dioxide (CO_2), methane and several other gases allow sunlight to pass through the atmosphere, but effectively absorb the infrared radiation re-emitted by the earth, thereby maintaining a higher atmospheric temperature. This much is generally accepted by the scientific community, although the degree and timing are subject to considerable debate.

The contribution of anthropogenic sources to the greenhouse effect is uncertain. What impact on temperature will increased CO_2 concentrations have? What steps can and should be taken to reduce the greenhouse effect? These questions are being debated by scientists and will continue to be debated for some time. There are no simple answers, nor will any one study provide answers to all the questions.

The primary focus of this inventory was anthropogenic CO_2 emissions in British Columbia for 1988 and 2005. This inventory included an estimate of CO_2 emissions from slash burning but it excluded some other anthropogenic sources such as burning of rangeland, burning for improvement of wildlife habitat, and accelerated decomposition of forest floor litter as a result of forest harvesting. Wildfires were not considered to be an anthropogenic source of CO_2 but this source is included for reference purposes. Natural CO_2 sinks were estimated for forests, rivers, wetlands and lakes. Reliable estimates of CO_2 releases from decomposition of dead organic matter could not be made for these ecosystems because of insufficient data.

The second focus of this study was to discuss the CO_2 reduction opportunities available, including the technologies and impacts associated with the most suitable options.

Other gases, such as methane and CFCs, also contribute significantly to the greenhouse effect. Opportunitites for controlling these gases also exist. It is not intended to diminish the importance of these other greenhouse gases in any way by solely focusing on CO_2 emissions, sinks and reduction opportunities. The impact of these other greenhouse gases may be the subject of future studies.

B. Scope of Work

The main project tasks were as follows:

1. Prepare an inventory of CO_2 from anthropogenic sources in B.C. for 1988. Contributions from individual source sectors are to be determined. The inventory will be prepared using accepted methodologies and the best available statistics.

2. Prepare an inventory of CO_2 absorption in the province using data for all vegetation and the annual carbon fixation typically achieved.

3. Develop forecasts for CO_2 sources and sinks in the year 2005 assuming no CO_2 reduction programs are implemented, but allowing for interfuel substitution which would normally occur.

4. Provide a list of CO_2 reduction opportunities and discuss the technologies and impacts associated with those considered to be most suitable.

II. METHODOLOGY USED FOR THE CO_2 EMISSIONS INVENTORY

A. CO_2 Emissions Sources

All CO_2 emission values are reported in units of kilotonnes (kt) CO_2. To convert to units of Carbon (C) multiply by 0.27. All sinks are reported in units of kt C. To convert to units of CO_2 multiply by 3.7.

1. Process Sources

CO_2 emissions resulting from a processing operation, specifically excluding combustion, are referred to here as process sources. Included are the following industries:

- clinker production in the cement manufacturing process;
- lime kilns;
- pulp and paper mills' lime production;
- methanol/ammonia production;
- aluminum smelting;
- CO boilers (petroleum refineries);
- other chemical processing industries;
- other miscellaneous sources.

The inventory of CO_2 emissions was developed usually by directly contacting the companies involved in the various processes. This was possible because only a few companies are involved in each of the process areas. In each case, descriptions were obtained of the processes which release CO_2 emissions to the atmosphere. Production data and CO_2 emission factors were also obtained where available.

(a) Cement Production

In the production of cement, calcium oxide (CaO) combines with silicates in clay or shale to form di- and tri-calcium silicates. In the production of Portland cement clinker calcium aluminates are also formed. The CaO is formed by heating $CaCO_3$, found in limestone, chalk or other material. One mole of CO_2 is released into the atmosphere in this process for each mole of CaO formed.

Production data and CO_2 emission factors were supplied by the manufacturers of cement in B.C., LaFarge and Tilbury. Production data and emission factors are confidential.

(b) Lime Kilns

In lime kilns, CaO is produced from $CaCO_3$ using a process similar to that used for cement manufacturing. Here, CaO is the final product. Process temperatures are much lower in lime kilns than in cement kilns, however this point does not affect the amount of CO_2 emitted.

As in cement kilns, one mole of CO_2 is emitted for every mole of CaO formed in the lime kiln. Consequently, the emissions are calculated by multiplying the ratio of the molecular weights of CO_2 and CaO (44/56) by the CaO production quantity.

The operators of lime kilns in B.C. (not including pulp and paper mills), Steele Brothers and Texada, supplied production data and their own emission factors which take into account process inefficiencies and product impurities.

(c) Lime Kilns in the Pulp and Paper Industry

The Kraft process is used to produce over 90% of the pulp in B.C. A simplified diagram of the Kraft pulping process showing CO_2 emissions from the lime kiln and from the recovery boiler is shown in Figure II-1. Briefly, in the Kraft process, wood is digested with caustic (NaOH) to produce pulp, but at only about a 45% yield. The remaining 55% of the wood leaves the process with inorganic chemicals as black liquor. This black liquor is burnt in chemical recovery boilers to produce process steam resulting in emissions of CO_2. This emission is included as a combustion source in the industrial process subsection. The inorganics (mainly sodium carbonate (Na_2CO_3)) from the recovery boiler are dissolved in water. Calcium hydroxide ($Ca(OH)_2$) is added to produce NaOH for use in the digestion process. The $CaCO_3$ precipitate from this reaction is converted into CaO in a lime kiln which is then dissolved in water to produce $Ca(OH)_2$ for use in the NaOH production.

CO_2 emissions from the lime kilns at pulp mills were estimated using a ratio of CaO generated per tonne of pulp produced, the ratio of molecular weights of CO_2 and CaO and then data for the amount of Kraft pulp produced annually. An analysis for B.C. pulp mills indicated that 0.27 tonnes to 0.35 tonnes of CaO are generated in lime kilns per tonne of pulp produced. Industry provided an estimate of 0.3 tonne CaO/t pulp. Based on these results a factor of 0.3 t CaO/t of pulp produced was used in this study to determine CO_2 emissions. The amount of pulp produced was supplied by the Canadian Pulp and Paper

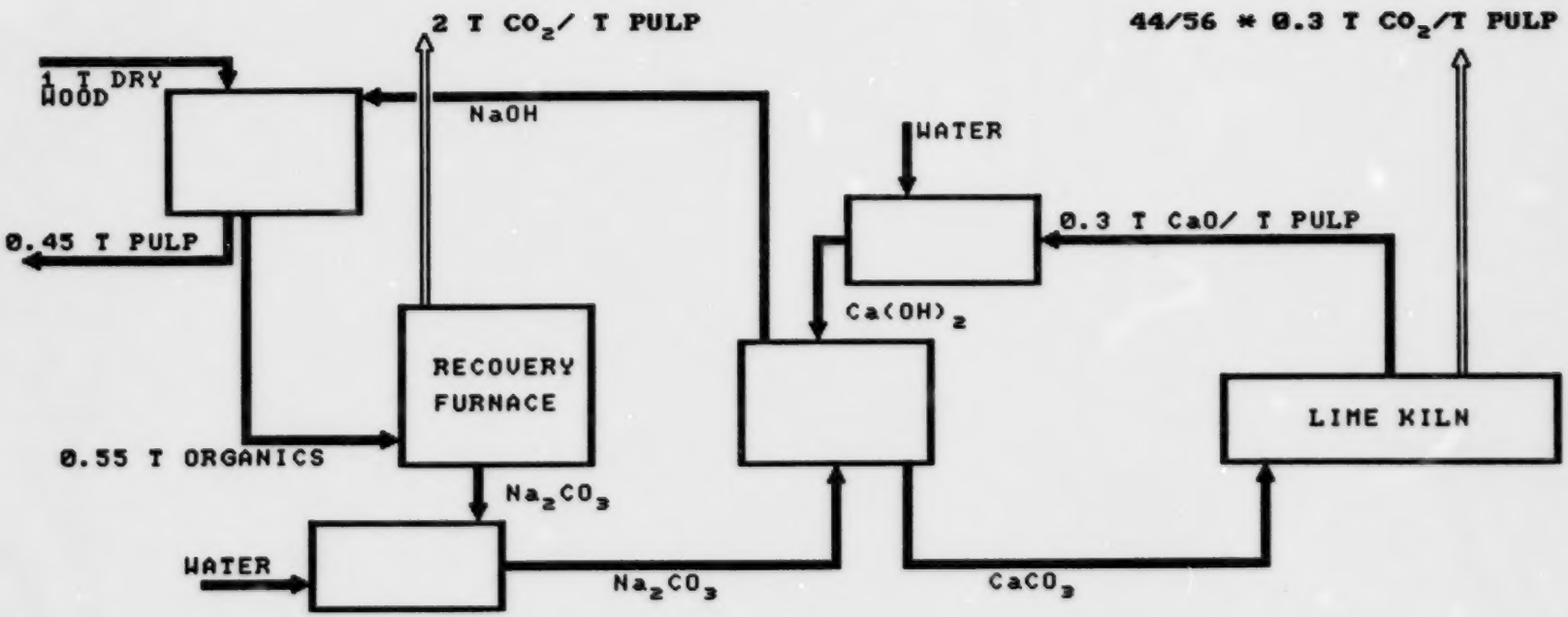


FIGURE II-1 PROCESS SOURCES OF CO_2 IN PULP AND PAPER PRODUCTION

Association as reported by the Council of Forest Industries of B.C. (1989).

(d) Methanol/Ammonia Production

Ocelot is the only company in this category currently operating in B.C. Cominco formerly operated an ammonia facility in the province but has since stopped production for economic reasons. Consequently, only the process used by Ocelot will be described.

Carbon dioxide is emitted from the Ocelot operation during the production of methanol from methane and steam. Other by-products include nitrogen (N_2), carbon dioxide and carbon monoxide (CO_2 and CO), hydrogen (H_2) and unconverted methane (CH_4). CO and CO_2 are emitted as by-products.

Ocelot reported the amount of CO_2 produced during a 350 day/yr production period. We assumed that all by-product CO would be converted to CO_2 within 0.4 yr (Jaques, 1989).

(e) Other Chemical Processing Industries

Other industries which potentially release CO_2 to the atmosphere as a result of a non-combustion process include:

- hydrogen production;
- sodium phosphate production;
- benzoic acid, sodium benzoate production (Chatterton Petrochemical).

Chatterton Petrochemical was the only plant identified which produced CO_2 as a by-product. They supplied an estimate of CO_2 emissions based on their production rates.

(f) Aluminum Smelting

Alcan releases significant amounts of CO_2 in their Soderberg pots. They provided an estimate of CO_2 emissions for 1988.

(g) CO Boilers (Petroleum Refining)

Crackers in the petroleum refining industry are sources of significant quantities of carbon monoxide (CO). This CO is diverted into CO boilers where it is burned to CO_2. An emission factor, supplied by one of the Lower Mainland refineries, was used to estimate total refinery CO_2 emissions from CO boilers.

(h) CO_2 Stripped from Natural Gas

Other miscellaneous sources of CO_2 emissions include:

- dry ice;
- liquid CO_2;
- compressed CO_2;
- CO_2 in fire extinguishers for fire fighting uses;
- CO_2 in carbonated drinks;
- CO_2 to control pH in waste water treatment plants;
- CO_2 stripped from natural gas.

Westcoast Energy Inc. supplied estimates of CO_2 quantities stripped from natural gas. Response was not received from other industries for inclusion in this report.

2. Stationary Combustion Sources

The CO_2 emissions resulting from the combustion of a fuel at a stationary location are referred to here as stationary combustion sources. The six sectors included in the inventory are:

- Gas utilities;
- Power (electricity) generation;
- Residential and agricultural;
- Commercial and public administration;
- Industrial;
- Fuel wood.

These subsectors agree with the breakdown used in Environment Canada's National Inventory of Sources and Emissions of CO_2 (1987) (Jaques, 1989).

(a) Gas Utilities and Natural Gas Producers

Emissions of CO_2 from gas utilities mainly arise from the combustion of fuel gas to run compressors and to power heaters and other processing equipment. Natural gas also contains a significant amount of CO_2 which is stripped out in order to meet product specifications. This stripped CO_2 is a source of emissions included in the process source category. Natural gas is also flared after completion of wells, during drill steam testing and during gas well testing.

The amount of natural gas consumed by producers and utilities for heating, processing and transmitting purposes including flared acid gas and sour gas was taken from Statistics Canada (The Crude Petroleum and Natural Gas Industry, 1988).

The amount of gas flared during testing is reported to Energy, Mines and Petroleum Resources (EMPR), by industry on the "S" forms. This information, however, is not compiled, and consequently was not available for this study. This will not significantly impact the estimate of CO_2 from gas utilities and natural gas producers.

(b) Power Generation

Estimates of energy output in B.C. were available from EMPR (1990). These are 1988 actual power generation data by the utilities, independent power producers and industry for their own use. The CO_2 emitted from thermal generation of electricity is only counted in this sector even though the electricity was used in an industrial sector.

Emission factors for each of the fuels used to generate electricity have been developed by Environment Canada (Jaques, 1990), Alberta Department of Energy (Burn, 1989), Energy, Mines and Resources (Lyman, 1989), Federal-Provincial Energy Ministers Task Force Report (1989) and Brookhaven National Laboratory (Steinberg and Cheng, 1987). Other volumetric or mass to energy conversion factors were taken from Statistics Canada (QRESD, 1988), and the National Energy Board (1988). Tables of these conversion factors are in Appendix I.

The conversion factors used assume stoichiometric conversion of the hydrocarbon fuel into CO_2 and H_2O. No assumptions were made to include actual conversion efficiency. Since CO is assumed to convert to CO_2 within 0.4 years (Jaques, 1989), there will be very little difference between actual CO_2 and the estimated CO_2.

CO_2 emissions were estimated by multiplying the energy output in petaJoules (PJ) by the fuel specific emission factor in kilotonnes (kt) CO_2 per petaJoule.

(c) Residential and Agricultural Sector

The residential and agricultural sector includes single detached and attached, apartment and mobile housing units. Energy use includes space heating, air conditioning, water heating, appliances and lighting requirements. Energy for heating private swimming pools are also included as energy usage.

The energy use data was supplied by EMPR (1990) for 1988. EMPR modified data reported by Statistics Canada (QRESD, 1988) to include apartment energy demand in the residential sector rather than in the commercial sector. The residential energy consumption accounts for about 92% of this sector.

CO_2 emissions were estimated by multiplying energy demand by the fuel specific emissions factor as discussed under part (b) Power Generation.

(d) Commercial and Public Administration Sector

The commercial and public administration sector includes finance, insurance, real estate, retail and wholesale trade, transportation and communication services, business services and personal services. The construction and utilities sectors are not included.

Energy use data was supplied by EMPR (1990). Their data source was Statistics Canada (QRESD, 1988). EMPR adjusted the Statistics Canada data to exclude apartment energy demand and to include light fuel oil (LFO) in the rail and marine subsectors and heavy fuel oil (HFO) in the rail subsector. These fuels were assumed to be consumed in a commercial activity rather than a transport activity. The commercial energy consumption accounts for about 88% of this sector.

As in the residential and agricultural sector, CO_2 emissions were estimated by multiplying the energy demand by the fuel specific emission factors.

(e) Industrial Sector

The industrial sector is divided into ten subsectors: pulp and paper, wood, primary metals, chemicals, non-metallic minerals, petroleum refineries, petrochemicals, other manufacturing, mining and other industries.

Energy demand data was supplied by EMPR (1990). Statistics Canada (QRESD, 1988) was the source of most of this data, however, industry specific data was used in some cases.

Emissions for all sectors were estimated by multiplying the energy demand by the fuel specific emission factors as discussed in Section (b), Power Generation.

(i) Pulp and Paper

The pulp and paper subsector includes integrated pulp and paper mills, pulp mills and product mills. Most are Kraft mills but there are also two chemi-thermomechanical pulp (CTMP) mills and one sulfite pulp mill.

Energy consumption for all fuel types at each of the 24 pulp mills in B.C. was available to EMPR from the Canadian Pulp and Paper Association in their Energy Monitoring Report (1988). The energy consumption values reported by each of the mills was summed and reported by EMPR (1990) without change.

Pulping liquors and hog fuel account for most of the energy consumption in the pulp and paper subsector. Electricity, heavy fuel oil, natural gas and small quantities of coal and coke, diesel and LPGs are also consumed.

CO_2 emissions from recovery boilers, which burn pulping liquors, were included in this sector. Environment Canada's report (Jaques) included these emissions in the process source category.

(ii) Wood Products

The wood products subsector includes lumber, plywood, particleboard, shake and shingle manufacturing. The sawmills in B.C. producing lumber account for about 80% of the output and energy demand in this subsector. Hog fuel supplies most of the energy requirements in the wood products subsector. Refined petroleum products, natural gas and electricity are also consumed.

EMPR used an internal survey to estimate hog fuel consumption. Their estimate only included hog fuel consumed to fire power boilers with energy recovery. Incineration of hog fuel was not included in their estimate. Instead, hog fuel incineration in included in solid waste disposal.

(iii) Primary Metals

The primary metals subsector produces aluminum, lead, zinc, silver, steel, copper and other metal products. Alcan and Cominco dominate this subsector, accounting for more than 90% of the energy consumption. Most of this energy, however, is self-generated, hydroelectric power. Small amounts of natural gas and refined petroleum products are also consumed.

(iv) Chemicals

The chemical industry in B.C. services primarily the forest products industry with bleaching agents and resins. Fertilizers and a wide range of miscellaneous products are also produced.

Electricity is the primary energy source for the production of bleaching agents. Cominco produces fertilizer as a means of reducing by-product gases to environmentally acceptable levels. The electricity consumed has been accounted for in the primary metals subsector. It is unclear whether the natural gas requirements, which are small, were included in the primary metals or chemicals subsectors.

(v) Non-Metallic Minerals

Cement manufacturers dominate the non-metallic minerals subsector. Glass and miscellaneous non-metallic mineral products manufacturers also consume relatively small amounts of energy.

There are three cement plants in the province. One plant utilizes the wet process which mixes materials in a wet slurry. The other two plants utilize the dry process, which has considerably lower total energy requirements. The dry process, however, consumes much more electricity than the wet process.

Note that the CO_2 emissions from this subsector include releases from fuel combustion, but exclude releases from the production of cement clinker, which is accounted for in the process source category.

(vi) Petroleum Refineries

A wide range of products are produced from B.C. and Alberta crude oil in B.C.'s six petroleum refineries.

Natural gas, electricity and "own" products (diesel, heavy and light oil) are the three types of energy consumed in the petroleum refineries. Natural gas and own products consumed in processes not involving fuel combustion, such as gasoline blending, are not included in these estimates of energy consumption. Any non-combustion releases would be included in the process source sector.

(vii) Petrochemicals

The Ocelot methanol/ammonia plant, which produces methanol from a natural gas feedstock, is the only plant in operation in this subsector. Natural gas is used as a petrochemical feedstock and as an energy source. The natural gas for energy is accounted for in the chemical industries subsector. Non-combustion CO_2 releases are included in the process source sector.

(viii) Other Manufacturing

This subsector includes all manufacturing industries not yet considered. They include food and beverages, rubber and plastic, clothing, textiles and leather, furniture and fixtures, printing and publishing, metal fabricating, machinery, transportation equipment and miscellaneous manufacturing.

Natural gas is the primary energy source for this subsector. Electricity and refined petroleum products are the other energy sources.

Only the CO_2 resulting from the combustion of fuels is included in this subsector. Non-combustion CO_2 emissions are included in the process source sector.

(ix) Mining

Coal, copper, lead, zinc, molybdenum, gold, silver and various other metallic and non-metallic minerals are produced in B.C.'s mining subsector.

Metal mines are more energy intensive than coal mines, requiring mainly electricity and diesel fuel. Coal mining operations use natural gas or refuse coal for drying purposes.

(x) Other Industries

Logging and construction are the industries included in this subsector. Diesel fuel oil and other refined petroleum products represent most of this subsector's energy requirements. Some electricity and natural gas are also used.

(f) Fuel Wood

Fuel wood consumption in B.C. for 1988 was estimated in two ways. In the first method, the number of households using wood as a principle fuel was multiplied by the average household energy requirements. A 50% heating efficiency was assumed (US EPA, AP-42). Statistics Canada (64-202, 1985) provided the estimates of households using wood. Heating requirements of 90 GJ/h (1985 Lower Mainland Emission Inventory for GVRD) were assumed for the average household.

In the second method, the amount of fuel wood in Canada (Statistics Canada, 25-201) was prorated to B.C. on the basis of the number of households using fuel wood as their principle fuel (Statistics Canada 64-002).

In both methods typical values for softwood of 20 MJ/kg and 395 kg/m^3 were assumed (Simons Resource Consultants and BHLA, Enfor Project C-258).

The estimate obtained from the first method was approximately 17% greater than that from the second. The estimate from the second method was used as the additional assumptions made in generating the first estimate, viz an average combustion efficiency and average heat loss per household in B.C., could be adjusted within reason to give the same result as the second method.

Consumption of fuel wood as a secondary source of energy would likely have a considerable impact on emissions from this sector. The overall CO_2 emissions, however, would differ by less than 1/2% of the reported estimate.

3. Mobile Combustion Sources

Mobile combustion sources have been divided into five sectors plus two fuel type groupings, to parallel the structure of the Environment Canada report (Jaques, 1989). The five sectors are: road, rail, marine, air and off-road. Natural gas and propane are the two fuel type groupings which apply mostly to the road sector and partly to the off-road sector.

Energy consumption data for each of the sectors was supplied by EMPR (1990). Statistics Canada reports (QRESD, 1988, PCFCS, 1988) were the source of the EMPR data.

CO_2 emissions were calculated by multiplying the energy consumption by the appropriate emission factor for the fuel used. It was assumed that all

CO was converted to CO_2. This assumption will not significantly impact the CO_2 estimate.

(a) Road

The road sector has been divided into eight vehicle type subsectors. Five of these vehicle type subsectors use gasoline and the other three use diesel fuel. This breakdown provides slightly better resolution than the Environment Canada report (Jaques, 1989) which only used seven categories.

The eight vehicle categories are defined in Appendix II-A according to US EPA definitions. For gasoline, the subsectors are:

- light duty gas vehicles (LDGV);
- light duty gas trucks 1 (LDGT1);
- light duty gas trucks 2 (LDGT2);
- heavy duty gas vehicles (HDGV);
- motorcycles (MC).

For diesel, the subsectors are:

- light duty diesel vehicles (LDDV);
- light duty diesel trucks (LDDT);
- heavy duty diesel vehicles (HDDV).

The energy consumption values for the road sector, provided by EMPR (1990), were apportioned to the eight vehicle type subsectors in the following manner:

- An active vehicle total population for B.C. was supplied by the Insurance Corporation of B.C. (ICBC) for 1988.

- The fractions of each vehicle type for this total vehicle population, the average vehicle-kilometres travelled for each vehicle type and the average fleet fuel efficiencies for each vehicle type were taken from the Lower Mainland Emission Survey for Mobile Sources (EAG, 1988) and assumed to remain unchanged between 1985 and 1988. These assumptions were necessary because the only information of this nature and detail available was provided by the Insurance Corporation of B.C. (ICBC) for 1985). Obviously, 1988 fleet fuel efficiencies have likely improved slightly over 1985. The error associated with this assumption is expected to be small since the fuel efficiencies of all vehicle types would improve. The breakdown provided in the Environment Canada report

(Jaques, 1989) could not be used for B.C. because B.C. has an older vehicle fleet than the Canadian average.

- The total kilometres travelled and the total litres of fuel consumed for each vehicle type subsector were calculated. The sum of the gasoline and the diesel consumption were compared to the EMPR values.

- This estimate was within 10% to 15% of the EMPR values, which seems reasonable. In order to estimate the energy consumption of each vehicle type subsector, the calculated fuel consumption totals were prorated to the EMPR fuel consumption total.

- Detailed calculations are in Appendix II-B.

(b) Rail

The major railways, Canadian Pacific (CP), Canadian National (CN) and B.C. Rail use diesel fuel, although B.C. Rail uses a small amount of electricity.

EMPR uses Statistics Canada data (QRESD, 1988) for the rail sector energy consumption, which includes only fuel purchased in the Province. Since CO_2 is emitted in B.C. as a result of fuel consumed in B.C., the fuel purchased in Alberta and consumed in B.C. must be added to the inventory. Likewise, the fuel purchased in B.C. but consumed in Alberta must be subtracted from the inventory.

Railways must keep track of fuel consumption within each province for tax purposes. All railways operating in B.C. were contacted for this information, and the total figures, as reported to the B.C. Ministry of Finance and Corporate Affairs, were obtained. The total reported by the railways was approximately 12.5% higher than that reported for tax purposes to the Ministry. The latter figure was assumed to represent the minimum. The former figure was used in the inventory calculation.

(c) Marine

The marine sector includes domestic and international shipping as well as fishing boats and pleasure crafts. Domestic shipping includes the marine carriers, B.C. Ferry Corporation, CP ferries and Ministry of Transportation and Highways' ferries. Vessels which are not "for hire", operated by oil or forestry companies, are not included in the marine sector. Instead they are included in the respective industrial subsectors.

EMPR (1990) supplied the energy consumption for the domestic and international shipping. These values were taken from Statistics Canada (QRESD, 1988). The energy consumption for fishing boats and pleasure craft was not included in the Statistics Canada publication. As with rail travel, only fuel purchased in B.C. was included in the Statistics Canada definitions, and hence EMPR, following these definitions, also only included fuel purchased in B.C. Since fuel is brought in from outside B.C. and also consumed outside of B.C. boundaries, the CO_2 estimate from this sector is expected to be higher or lower than actual. This sector accounts for 2.3% of the total CO_2 emissions. Consequently, even a large difference between consumed and purchased fuel will only have a minor impact on overall CO_2 emissions.

(d) Air

The air sector includes all aircraft flying scheduled and chartered, international and domestic routes, as well as government and private aircraft. Aviation gasoline and turbo fuels are the only fuels used.

EMPR (1990) supplied the quantity of fuel consumed by this sector. Their data, taken from Statistics Canada (QRESD, 1988) includes the fuel purchased in B.C. Consequently, the data should be adjusted to account for fuel purchased in B.C. but consumed outside the province and fuel purchased outside of B.C. but consumed inside the province. Unfortunately, this was not possible with the information available to us. The difference between purchased and consumed fuel estimates will not have a significant impact on total CO_2 emissions for reasons discussed above under marine sources.

(e) Off-Road

The off-road sector includes construction, logging, mining, agricultural, recreational and home uses of fuel.

Statistics Canada (53-218, 1988) provides data on retail pump sales, both net, with road use tax, and gross, with and without tax. The difference was taken to be off-road use. Some of this off-road fuel quantity was probably consumed in pleasure boats. Bulk sales for off-road use were also not reported by Statistics Canada. Consequently, adjustments to the data would be required. Insufficient data was available for a satisfactory accounting of these sources. This source is so small that even if a significant amount of fuel was used in pleasure boats, it would have little impact on any other source sectors.

(f) Natural Gas and Propane

Natural gas is used in a variety of motor vehicles, either as the only fuel source or as an alternative fuel source. Insufficient data was available to include natural gas use in the road sector, apportioned to the various vehicle types. Instead, Statistics Canada (QRESD, 1988) values of natural gas consumption for transportation purposes were used to calculate CO_2 emissions from the combustion of these fuels for the transportation sector in general.

4. Solid Waste Disposal

Solid waste disposal was divided into four sectors: municipal, industrial and wood waste incinerators and landfill gas.

(a) Municipal

The GVRD refuse incinerator accounts for most of the municipal solid waste (MSW) incinerated in the province. This incinerator began operating in 1988. Other incinerators are located at Comox, Kent, Cowichan Valley, Duncan, Ladysmith and Tumbler Ridge.

The GVRD reported the quantity of MSW incinerated in the GVRD in 1988. Other quantities were estimated from the Municipal Solid Waste Task Force Report (1989).

Solid waste is a very heterogenous waste. Carbon content and heating values of the incoming waste can vary widely. A conversion factor relating CO_2 emissions to solid waste quantities was taken from Environment Canada (Jaques, 1989). A value of 0.9 t CO_2/t solid waste was used.

(b) Landfill Gas

Most refuse is landfilled in B.C. Depending on the conditions in the landfill, especially moisture content, some or much of the decomposible fraction of solid waste will be converted to CO_2 either aerobically or anaerobically. This decomposition process takes place over the life of landfill and continues for many years after the landfill is closed. The amount of landfill gas produced today actually depends on quantities of solid waste landfilled years ago. Since these quantities cannot be estimated, we have assumed that the amount of landfill gas produced is proportional to current solid waste generation rates. The quantity landfilled was taken from the Municipal Solid Waste Task Force Report (1989). An emission factor of 0.17 t CO_2/t solid waste was estimated based on values reported from the literature (Ham, 1979).

(c) Industrial and Institutional

This category includes incineration by industries, institutions and other non-municipal incineration (i.e. international air and marine waste). Because of strict laws regulating the air emissions from incinerators in the GVRD, most, if not all, apartment incinerators and industrial incinerators have been shut down. The B.C. Ministry of Environment was unable to supply any additional information concerning industrial incineration for the rest of B.C. Hospital incineration of biomedical wastes was the only institutional source in this sector for which some information was available.

The amount of biomedical waste incinerated in B.C. was taken from the B.C. Task Force on Biomedical Waste Management (1989). GVRD permit data was used to estimate international solid waste disposal rates. Environment Canada's (Jaques, 1989) conversion factor of 0.9 t CO_2/t solid waste was assumed.

(d) Wood Waste

Wood waste, or hog fuel, is generated primarily at the numerous sawmills around the province. Much of this is consumed by the sawmills or is shipped to pulp mills for pulp or energy production. These quantities are included in the pulp and paper and wood products subsectors under stationary combustion.

A considerable amount of surplus hog fuel is not utilized for energy production, manufactured products or other uses. Instead, this surplus hog fuel is either disposed of in landfills, or, more commonly, incinerated in beehive burners.

There are two sources of surplus hog fuel statistics. The EMPR (1986 or 1990) have estimates which were generated by the pulp and paper industry and internal surveys. Alternatively, surveys based on 1985 and 1986 production of hog fuel by Appleby (1987, 1988) provides a mill by mill breakdown and disposition of hog fuel in B.C. The latter source was deemed to be the most complete accounting of wood waste quantities. The wood waste quantity estimate from the past survey was considerably higher than that reported by EMPR.

5. Prescribed Burning

Prescribed burning for silvicultural purposes, improvement of wildlife habitat and rangeland, and for control of fire hazards was considered under this category. Wildfire CO_2 releases were included for reference, but are not considered an anthropogenic source. CO_2 emissions from these sources were

calculated using data from the Pacific Forestry Centre of Forestry Canada (Hawkes, 1989, Comeau, 1990, Bedford, 1990, Lawson, 1990) and the B.C. Forest Service (Fuglen, 1990). Burning of slash for silvicultural purposes is the largest CO_2 source in this category. Burning for wildlife and range improvement releases a small amount of CO_2 because of low fuel loading. A similar amount of CO_2 would be released if the material now incinerated by prescribed burning was allowed to decompose naturally, but this would occur over a different time frame.

B. CO_2 Sinks

The carbon cycle involves an exchange of carbon between the atmosphere and various reservoirs on the earth. One part of this exchange is the emission of carbon, in the form of carbon dioxide, to the atmosphere as a result of fossil-fuel use, deforestation, decomposition of organic matter, and other biological and physical processes. The other part of this exchange is the annual removal of atmospheric CO_2 and its accumulation in reservoirs or sinks on the earth's surface. Atmospheric CO_2 is continuously being absorbed by green plants and by chemical and biological processes in the oceans (Schneider 1989). To estimate the rate at which carbon is captured and stored in various ecosystems, one needs to estimate net primary productivity, which is the amount of organic matter left after one subtracts natural respiration losses of CO_2 from the total amount of CO_2 fixed by photosynthesis (gross primary productivity).

In British Columbia, the major sink for atmospheric CO_2 is the forest. Other lesser sinks are rivers, lakes, estuaries and wetlands. Agricultural ecosystems are not included because, except for orchard trees, they are typified by rapid accumulation and removal of biomass with no opportunity for long-term accumulation of carbon as in a forest. Despite this very short term cycle of carbon capture and release, typically a year for much agricultural biomass, it does not mean that agricultural ecosystems could be ignored if one were to undertake a more detailed inventory of CO_2 emissions and sinks. For example, there is some carbon storage in root systems of perennial agricultural crops. Also, conversion of forest land to agricultural uses contributes to accelerated loss of soil carbon and increased release of this carbon to the atmosphere (Schlesinger 1977, Kimmins 1987). Swift et al. (1979) reported an example of continuous cropping of wheat over a 30-year period which reduced soil organic content by 63% from its original level. Fortunately this trend can be reversed, given enough time. For example, in 1881 at Rothamsted in England a wheat field on which cereal cropping had occurred for a long time was allowed to revert to natural woodland. Soil carbon in the upper 23 cm had risen from 0.98% in 1881 to 2.7% in 1964 (Russell 1973).

Taken together, the various carbon sinks are important because they help to counter-balance the increasing addition of CO_2 to the atmosphere from human

activities. Since these sinks are highly variable in terms of photosynthesis, respiration and storage or transport of organic carbon, estimates of carbon accumulation are subject to considerable error and should not be accepted uncritically.

1. Forest Sector

A preliminary estimate of the carbon balance for British Columbia's forests was recently prepared by Comeau (in prep A). To estimate the annual rate of carbon fixation by forests, Comeau compared the standing crop of merchantable wood in 1981 and 1986, using inventory data from the British Columbia Ministry of Forests. Over 1 billion m^3 of merchantable wood accumulated on the province's 45 million ha of inventoried forest land in that 5-year period. This accumulation of wood, when converted to carbon content, represented an average annual gross increment of 53×10^6 tonnes of carbon per year. Comeau estimated that harvesting annually removed 14×10^6 tonnes of carbon per year and wildfire losses released 1×10^6 tonnes of carbon per year, leaving a net increment of 38×10^6 tonnes of carbon per year. The figure of 53×10^6 tonnes of carbon per year for total forest growth is likely an underestimate because Comeau's methods did not include estimates of carbon accumulated in non-merchantable parts of the tree or in sub-merchantable forests, nor in root systems and understorey vegetation.

For the present report, a method different from Comeau's was deliberately selected to determine whether an independent approach would give a comparable estimate of annual carbon fixation by British Columbia forests. Comeau's estimates of CO_2 emissions from forests as a result of burning and harvesting were not re-evaluated in the CO_2 sink portion of this project.

Growth data presented by Smith (1976) were used as the basis of the present analyses and are reproduced, after metric conversion, in Appendix III. The latter author gave the annual growth of different species groups for immature and mature forests in the coastal and interior regions of B.C. Smith estimated the total amount of wood plus bark for a given volume of merchantable wood and he also provided expansion factors to estimate nonmerchantable materials and submerchantable trees for the main species groups in the province. Thus, this data source has the advantage of providing an estimate of other components besides tree stems.

The original intent was to apply Smith's data to the British Columbia portion of two recent inventories of Canada's forests (Bonnor 1985; Forestry Canada 1988). However, these inventory reports do not give a complete breakdown of the province's forests by species groups and maturity classes. To make full use of Smith's (1976) report, the inventory report by Bickerstaff et al. (1981) was used as a first approximation. The latter report includes tables that provide data on areas of different maturity classes and volumes of major tree species in 12 inventory biozones within British Columbia. Unfortunately,

this may not be a very precise database because the proportions are only in tenths of volume or area and therefore have relatively large margins of error.

The procedure for estimation of potential CO_2 sinks in British Columbia forests is described in Appendix III. These steps are briefly summarized here. From the proportion in volume of each major forest species given in Table 6 of Bickerstaff et al. (1981), the proportion of area occupied by each species group was estimated. Each of the latter proportions was then converted to absolute area for the following computation. Using the values given in Appendix III, the area of each species group was multiplied by the annual growth rate of bolewood (in volume per unit area) to obtain an estimate for the annual volume growth of bolewood in each species group. After converting the volume values to values of biomass of bolewood plus bark (Appendix III) each of the latter values were multiplied by an expansion factor to account for growth in all other above-ground biomass components and submerchantable trees. Finally, the total annual growth in biomass was converted to annual growth in carbon.

2. River Sector

The many rivers in British Columbia transport a substantial amount of carbon to the ocean. However, a small fraction of the suspended organic carbon (SOC) and POC may reside in the river channel and floodplain sediment for a fairly long time. There is no information available to estimate the storage of these forms of carbon in B.C. rivers. However, there are sufficient data to allow for the estimation of the amount of total organic carbon (TOC) transported by B.C. rivers to the shallow sea. It is estimated that about 80% of this carbon ends up in the sediment of the continental shelf (Garrels and Mackenzie 1981). For this report, as in estuarine systems, movement to the ocean of carbon that has been captured by photosynthesis in the river system was regarded as a potential sink of carbon.

There is a close relationship between the annual river discharge and the load of TOC transported by the river to the ocean (Mulholland and Watts 1982; Schlesinger and Melack 1981; Meybeck 1981). For rivers in North America, this relationship was given by Mulholland and Watts (1982) as,

$$\log Y = 1.0 (\log X) + 0.86 \qquad (1)$$

where X is the mean annual discharge and Y is the annual TOC load. The weighted mean annual TOC concentration inherent in this relationship, about 6.5 g C m^{-3}, is approximately constant over the range of mean annual discharges compiled by Mulholland and Watts (1982). Equation (1) was used to estimate the mean annual TOC load of rivers in B.C. Mean annual discharges of the major rivers in B.C. were compiled from the Hydrological Atlas of Canada (Fisheries and Environment Canada 1978) and other sources

(Hoos and Packman 1974; Hoos and Vold 1975; Bell and Kallman 1976; Hoos 1976; Bell and Thompson 1977; Farley 1979).

When estimating the magnitude of the river-borne TOC sink it is important to avoid double counting of the carbon derived from sources outside the river system (Thurman 1986). Using the concentration of TOC in river water measured in the dry season is one way to minimize the contribution from terrestrial sources. This value is about 3 to 6 g C m^{-3} for rivers on Vancouver Island (Bell and Thompson 1977; Naiman and Sibert 1978), and about 1.5 to 3.7 g C m^{-3} in the Fraser and Squamish rivers (Benedict et al. 1973).

For the present estimates, the computed annual TOC loads in rivers were reduced proportionately from the overall mean concentrations to the dry season values. Thus, for rivers in Vancouver Island, the calculated annual TOC loads were multiplied by factors of 0.5 and 0.6 to lower the value of 6.5 g C m^{-3} to 3 to 3.5 g C m^{-3}. For rivers on the mainland, factors of 0.25 and 0.6 were applied to those rivers that drain within or close to the border of British Columbia. The latter two factors reduced the mean TOC level from 6.5 g C m^{-3} to 1.5 to 3.7 g C m^{-3}. For the Columbia River and the few rivers in the north of which only their headwaters are in B.C., a factor of 0.25 was used, i.e. assuming a TOC concentration of 1.5 g C m^{-3}.

3. Wetlands Sector

The permanent burial of organic matter in soil and of sediments in fresh water or shallow marine ecosystems are potential sinks for carbon. When decomposition of organic matter is retarded by water, as occurs in wetlands, then peat begins to accumulate. The amount of carbon stored annually as peat can be estimated simply by multiplying the rate of peat accumulation (in grams of carbon per unit area) by the total area of peatland if both these values are available.

In estuarine systems, only a very small fraction of the annual plant production is buried in the sediment within the system. More than half of the plant litter, in both particulate and dissolved forms, is exported to the continental shelf. About 80% of the total carbon exported would be buried in coastal sediment (Garrels and Mackenzie 1981). For the present analyses, the latter flux of organic carbon was regarded as a potential sink of carbon. This flux is estimated as the annual loss of net primary production in estuarine ecosystems.

4. Lakes Sector

Freshwater bodies, such as lakes and impounded reservoirs, are also potential carbon sinks. In a lake ecosystem, the dissolved organic carbon is used for photosynthesis by various aquatic plants and algae. A small

percentage of the plant debris or particulate organic carbon (POC) usually sinks to the bottom and then is buried in sediment. In British Columbia the carbon balance of Marion Lake, in the University of British Columbia Research Forest near Haney, is known in sufficient detail to allow for carbon flux estimation. This review did not reveal similar data from other British Columbia lakes. Therefore, it was necessary to extrapolate results from Marion Lake to the other freshwater lakes in the province.

The amount of carbon stored in the bottom sediment can be estimated if one knows the flux of carbon to the sediment and the area of the lake. For Marion Lake, the sedimentation rate of POC was measured at about 8 g C m^{-2} yr^{-1} (Efford and Hall 1975; Richey et al. 1978). Alternatively, sedimentation rate can also be estimated by assuming that 10 to 15% of the net primary production in a lake would accumulate in sediment (Mulholland and Elwood 1982). For Marion Lake, the primary production was estimated to be 80 g m^{-2} yr^{-1} (Efford and Hall 1975; Richey et al. 1978). Studies on other small lakes by Nidle et al. (1984) produced similar results: 65 g C m^{-2} yr^{-1} for Sproat Lake and 80 g C m^{-2} yr^{-1} for Kennedy Lake. Application of the 10 to 15% factor would indicate that the sedimentation rate is in the range of 6.5 to 12 g C m^{-2} yr^{-1}.

III. CO_2 INVENTORY FOR 1988

A. CO_2 Emissions

1. Annual CO_2 Emissions by Source Sector

Stationary combustion sources are the largest emitters of CO_2 (Figure III-1), accounting for 49% of the total anthropogenic CO_2 emissions. Mobile sources are the next largest source of CO_2, amounting to 17,412 kt, or 21% of the total. Prescribed burning is the third largest emitter of CO_2, contributing 16% of the total. The smallest source category is process sources, which emit 3239 kt of CO_2, or 4% of the total.

The total anthropogenic CO_2 emissions in B.C. for 1988 were estimated at 84,380 kt CO_2. This is 23,316 kt, or 38%, more than the 61,060 kt CO_2 in B.C. reported for 1987 in Environment Canada's inventory (Jaques, 1989). The two inventories are compared in Table III-1 for the major source sectors (a complete detailed comparison is in Appendix IV). Significant differences between the inventories exist in the stationary combustion, solid waste incineration and prescribed burning source groups.

A partial comparison was also possible using Energy, Mines and Resources' (EMR) Vision 2020 Energy Supply and Demand Forecast for B.C., Yukon and Northwest Territories. Emissions for several sectors for which energy consumption data was available, were calculated and compared to the National Inventory and this inventory in Table III-2. It is clear that the major difference between the three inventories is in the industrial sector CO_2 emission estimates.

The inventory using EMPR energy consumption values for the industrial sector is higher than it would be if EMR values were used. Environment Canada's inventory values are more in line with the EMR values. This discrepancy of over 7,000 kt CO_2 is explained partially by the more than 5,500 kt CO_2 from hog fuel consumption which was included in the EMPR values but not in the EMR or Environment Canada estimates.

A significant contributor to the difference between this inventory and Environment Canada's inventory is in the amount of CO_2 estimated from prescribed burning. The estimate calculated from data provided by the B.C. Ministry of Forests is 6,139 kt CO_2 higher than the estimate reported by Environment Canada for 1987. It should be noted that these estimates were for two different years, 1988 and 1987. Furthermore, estimates of this nature are very crude and could easily differ by 100%. Because of the size of this

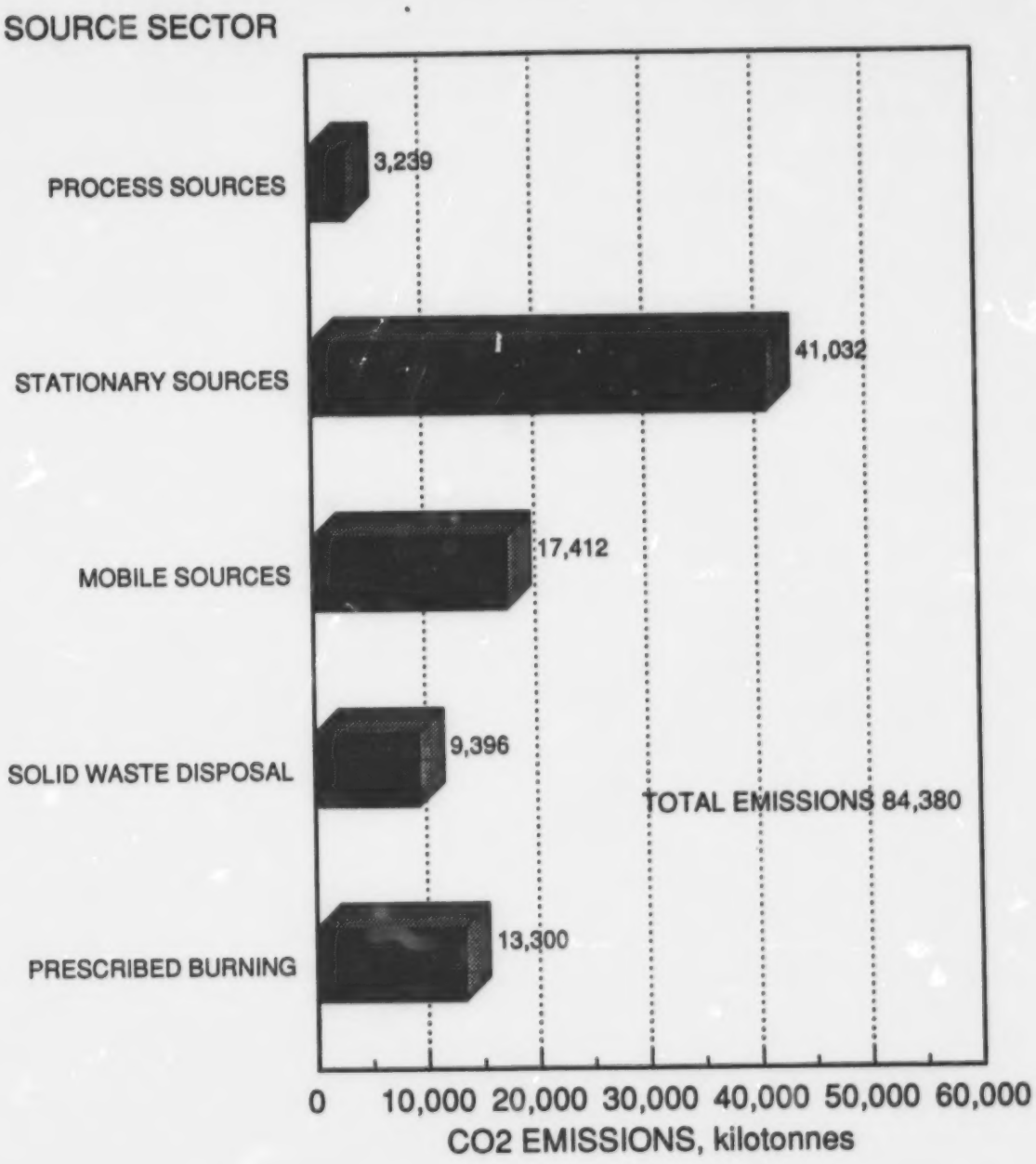


FIGURE III-1 CO2 EMISSIONS BY MAJOR SOURCE SECTOR IN BC (1988)

TABLE III-1 COMPARISON WITH NATIONAL INVENTORY ESTIMATES FOR BC BY MAJOR SOURCE SECTOR

kilotonnes CO2

	THIS STUDY	
	EMPR	ENV.CAN.(1987)
PROCESS	3,239	816
STATIONARY SOURCES	41,033	29,226
MOBILE SOURCES	17,412	18,243
SOLID WASTE DISPOSAL	9,396	5,619
PRESCRIBED BURNING	13,300	7,161
TOTAL	84,380	61,064

TABLE III-2 COMPARISON OF THIS STUDY, EMR, & ENVIRONMENT CANADA VALUES FOR SELECTED SECTORS

kilotonnes CO2

	THIS STUDY		
	EMPR	EMR	ENV.CAN.(1987)
RESIDENTIAL/AGRIC.	4,631	4,415	3,556
COMM./PUB. ADMIN.	2,748	3,863	2,645
INDUSTRIAL	29,443	22,927	20,845
ROAD	11,232	11,345	14,459
RAIL	1,589	837	785
MARINE	2,068	1,650	860
AVIATION	2,165	1,962	1,904
OFF-ROAD	358	48	235
TOTAL	54,234	47,044	45,326

difference (about 10% of Environment Canada's inventory) efforts are needed to better resolve the estimation methodology.

The last major difference between the two inventories is in the estimate of CO_2 from wood waste incineration. The estimate of CO_2 emissions made in this study for wood waste incineration is 3,300 kt CO_2 higher than that for Environment Canada's inventory. Environment Canada based their estimate on the amount of lumber produced. Surveys of the B.C. sawmills were used to estimate wood waste quantities in this inventory.

Other differences included the following additional estimates in this inventory:

- 2,400 kt CO_2 from process sources;
- 700 kt CO_2 from power generation;
- 1,100 kt CO_2 from the residential/agricultural sector;
- 300 kt CO_2 from fuel wood consumption;
- 800 kt CO_2 from the rail sector;
- 500 kt CO_2 from municipal incineration and landfill gas.

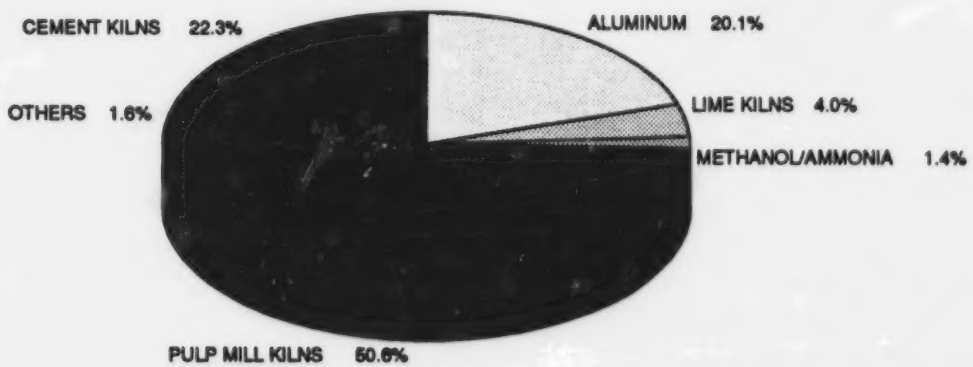
The total difference accounted for in the above discussions is about 20,700 kt CO_2. This represents about 90% of the difference between the two inventories.

(a) Process Sources

Process sources account for less than 4% of the total emission, or 3,239 kt CO_2. CO_2 emissions from the eight sectors are listed in Table III-3 and depicted in Figure III-2. Lime calcination in kilns in the pulp and paper, cement and lime kiln industries account for over 75% of the process CO_2 emissions in B.C. for 1988. The bulk of the remaining process CO_2 emissions result from aluminum smelting. Chemical industry and gas production releases of CO_2 are relatively insignificant. CO_2 emissions also arise from dry ice use, liquid CO_2 use, fire extinguishers, etc. No estimates were available for these sources. Consequently, the process emissions estimates are considered to be low.

TABLE III-3 PROCESS SOURCES OF CO2 EMISSIONS IN BC (1988)

	kilotonnes CO2
CEMENT KILNS	723
OTHERS	53
PULP MILL KILNS	1,638
METHANOL/AMMONIA	46
LIME KILNS	129
ALUMINUM	650
TOTAL	3,239



OTHERS INCLUDES CHEMICAL & CO BOILERS

FIGURE III-2 PROCESS SOURCES OF CO2 EMISSIONS IN BC (1988)

(b) Stationary Combustion Sources

Stationary combustion sources contribute 41,030 kt CO_2, or 49% of the total CO_2 emissions in B.C. for 1988. The CO_2 emissions from the six sectors are reported in Table III-4 and shown in Figure III-3.

Industrial source CO_2 emissions are the largest sector by far, accounting for 72% of the stationary combustion source CO_2 emissions. CO_2 emissions from the nine subsectors are reported in Table III-5 and illustrated in Figure III-4. Residential/agricultural and commercial/public administration account for 11% and 7% of the stationary source emissions, respectively.

(c) Mobile Combustion Sources

Mobile combustion sources are the second largest contributor of CO_2 emissions at 21%. In B.C. for 1988, 17,410 kt CO_2 are emitted from this source. CO_2 emissions for the five sectors and two fuel types are reported in Table III-6 and shown in Figure III-5.

Road vehicles account for 63% of the mobile combustion source emissions, omitting natural gas and propane use. Air, marine and rail sector emissions account for 12%, 12% and 9%, respectively.

Light duty gasoline vehicles are the largest contributor of CO_2 emissions in the road sector. They emit 5,188 kt CO_2, accounting for 48% of the road sector CO_2 emissions.

(d) Solid Waste Disposal

Solid waste disposal in B.C. accounts for 11% of the total anthropogenic CO_2 emissions for 1988. Wood waste (hog fuel) incineration account for 94% of the 9,396 kt CO_2 emitted from solid waste disposal activities. Table III-7 lists the CO_2 emissions from this sector. These emission sources are illustrated in Figure III-6.

(e) Prescribed Burning

Prescribed burning is the third largest contributor of CO_2 emissions. The 13,300 kt CO_2 emitted, accounts for 16% of the total anthropogenic CO_2 emissions in B.C. for 1988. As detailed in Appendix II-C, 11,100 kt CO_2 were emitted from slash burning for silvicultural and fire control purposes, accounting for 83% of the total from prescribed burning. Range and wildlife area enhancement contributes 2,200 kt CO_2. Forest fires in 1988 were at an all time low, contributing only 350 kt CO_2. Typically, forest fires would contribute about 4,300 kt CO_2.

TABLE III-4 STATIONARY COMBUSTION SOURCES OF CO2 EMISSIONS IN BC (1988)

	kilotonnes CO2
GAS UTILITIES	2,410
POWER	1,133
RESIDENTIAL/AGRIC.	4,631
COMM./PUB.ADMIN.	2,748
INDUSTRIAL	29,443
FUEL WOOD	667
TOTAL	41,033

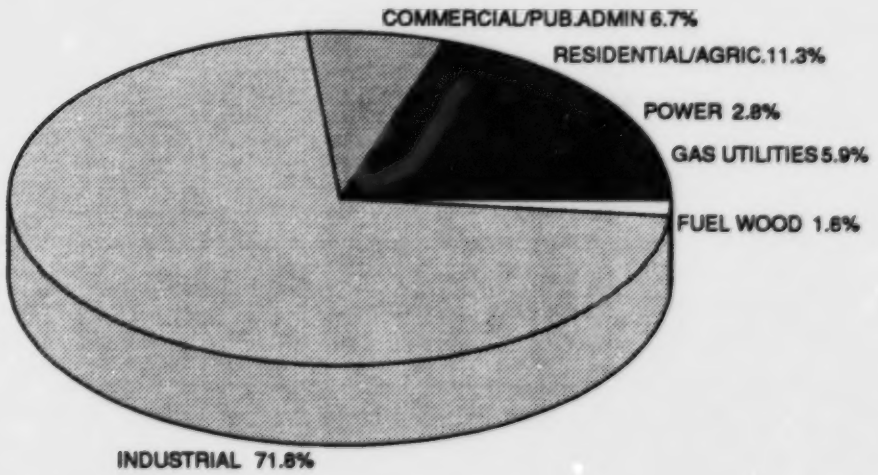
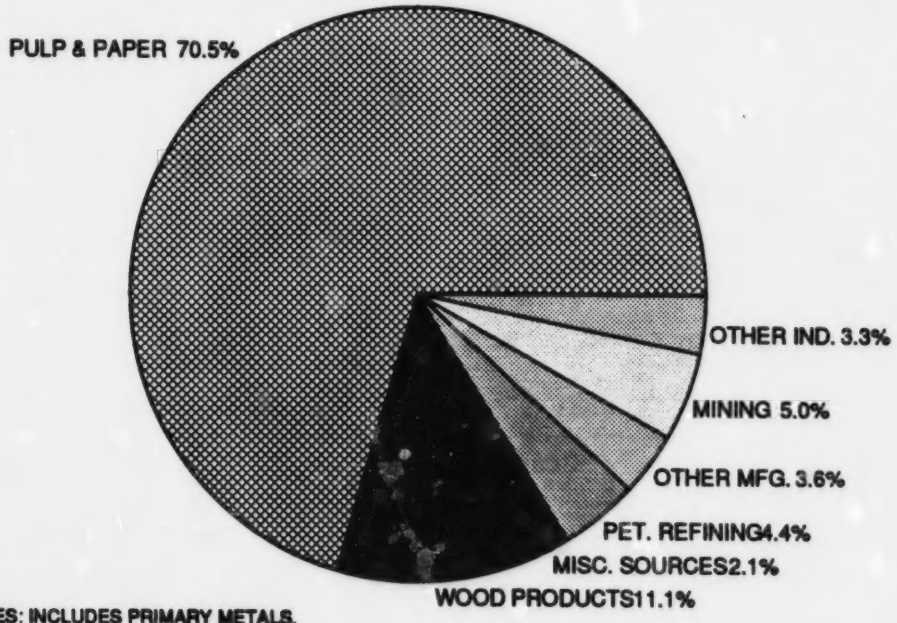


FIGURE III-3 STATIONARY COMBUSTION SOURCES OF CO2 IN BC (1988)

TABLE III-5 INDUSTRIAL SECTOR CO2 EMISSIONS IN BC (1988)

	kilotonnes CO2
PULP & PAPER	20,767
WOOD PRODUCTS	3,281
MISC. SOURCES	610
PET. REFINING	1,304
OTHER MFG.	1,052
MINING	1,462
OTHER IND.	967
TOTAL	29,443



MISC. SOURCES: INCLUDES PRIMARY METALS, CHEMICAL, & NON-METALLIC INDUSTRIES

FIGURE III-4 INDUSTRIAL SECTOR CO2 EMISSIONS IN BC (1988)

TABLE III-6 MOBILE COMBUSTION SOURCES OF CO2 EMISSIONS IN BC (1988)

	kilotonnes CO2
ROAD	11,232
RAIL	1,589
MARINE	2,068
NATURAL GAS / LPG	344
AIR	2,165
OFF-ROAD	358
TOTAL	17,412

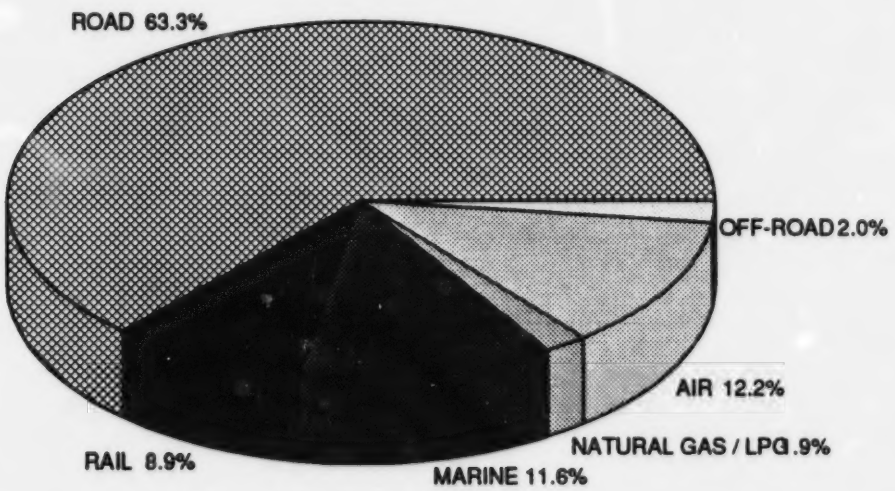


FIGURE III-5 MOBILE COMBUSTION SOURCES OF CO2 EMISSIONS IN BC (1988)

TABLE III-7 SOLID WASTE DISPOSAL SOURCES OF CO_2 EMISSIONS IN BC (1988)

	kilotonnes CO_2
MUNICIPAL INCINER.	243
INDUSTRIAL INCINER.	14
LANDFILLS	311
WOOD WASTE	8,828
TOTAL	9,396

MUNICIPAL INCINERATION INCLUDES:
2.5% MUNICIPAL AND 0.1% INDUSTRIAL INCINERATION

FIGURE III-6 SOLID WASTE DISPOSAL SOURCES OF CO_2 EMISSIONS IN BC (1988)

2. Ranking of CO_2 Emissions

CO_2 emissions for all sectors and subsectors by order of rank are reported in Figure III-7. The top five sources account for 70% of the total anthropogenic CO_2 emissions for 1988.

3. Annual CO_2 Emissions by Fuel Type

The 67,840 kt CO_2 emitted as a result of fuel combustion accounts for 80% of the total anthropogenic CO_2 emissions in B.C. for 1988. The remaining 16,540 kt CO_2 were emitted either from process sources or prescribed burning. The top five fuel types account for almost 85% of the total CO_2 emissions from fuel combustion (Figure III-8). Hog fuel (including wood waste incineration without energy recovery) and pulping liquors account for over 43% of the CO_2 emissions from fuel combustion and 35% of the total CO_2 emissions. Natural gas, accounting for 18% of fuel combustion CO_2 emissions, was followed by motor gasoline and diesel fuel at 13% and 11%, respectively.

Fossil fuels account for 44% of the total CO_2 emissions or 55% of the fuel combustion CO_2 emissions in B.C. for 1988. Biomass, including wood waste, hog fuel, solid waste, but excluding pulping liquors, account for 19% of the total CO_2 emissions or 23% of the fuel combustion CO_2 emissions. Coal accounts for less than 1% of the total CO_2 emissions, or 1% of the fuel combustion CO_2 emissions. This is included in fossil fuels total above.

4. Uncertainty of Emissions

Uncertainty exists in any estimates made of emissions of pollutants as with estimates of any randomly varying quantity. The uncertainty in estimates of air emissions has two components, these being precision uncertainty and bias uncertainty (Horie, 1988). Precision uncertainty refers to the error in estimating the mean of a random variable. Bias uncertainty reflects the inaccuracy of the estimated mean from the true value, which is seldom known. Bias arises because of systematic errors in the estimation methodology, which may lead to over- or under-estimation of the true value, that cannot readily be determined because no direct measurements of the random quantity are available.

A pseudo Delphi methodology was used to estimate precision uncertainty in the 1988 CO_2 emissions inventory. Company engineers involved in the study, and peers and supervisors provided estimates of uncertainty for each of the five inventory categories. Estimates were based on their intimate knowledge of the procedures involved or brief descriptions written by those involved. A two-stage iterative process was used where individuals were given the opportunity to revise their estimate after reviewing the estimate of others. The individual uncertainty estimates were assigned by excluding high and low

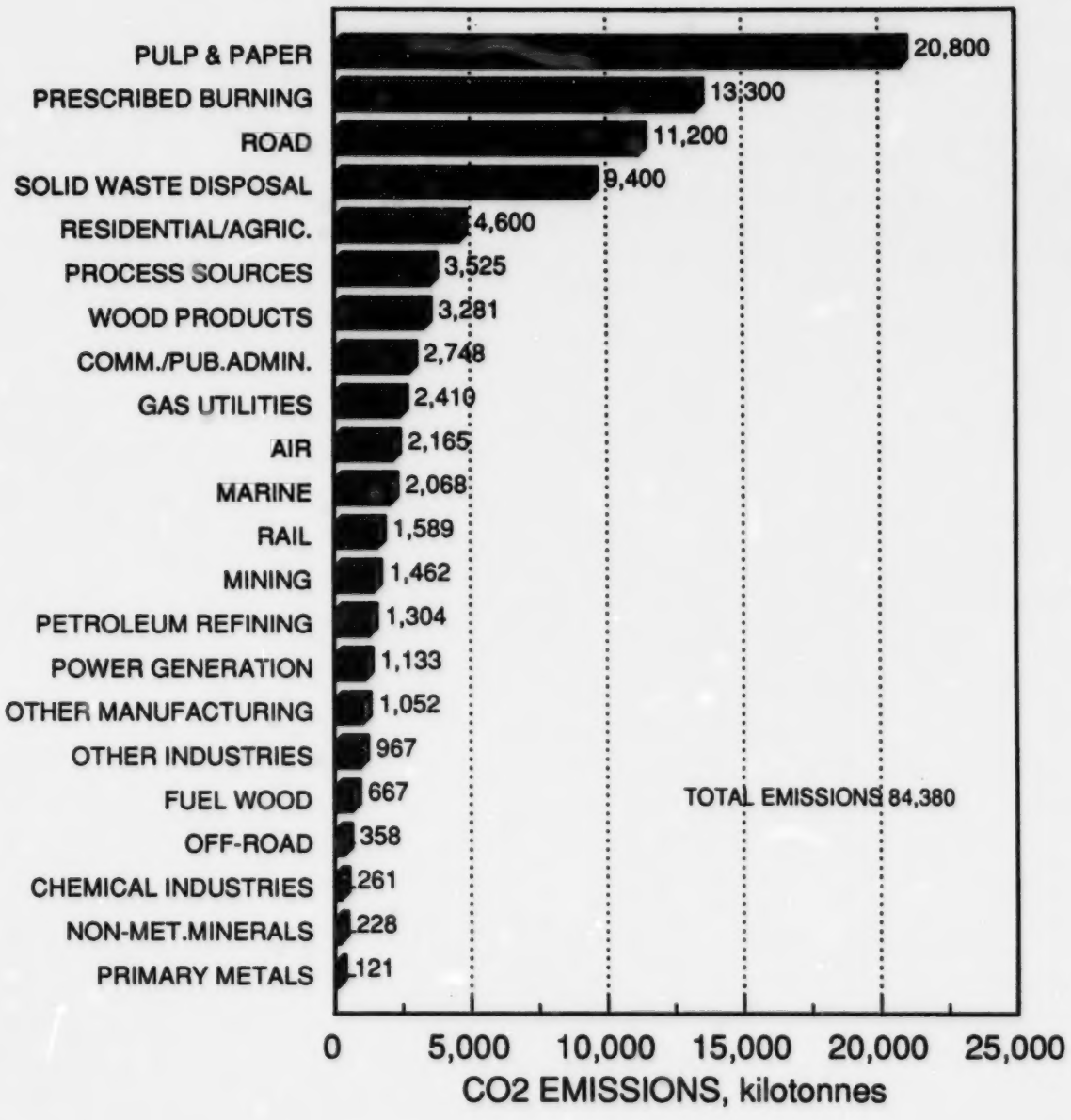


FIGURE III-7 CO2 EMISSIONS BY SOURCE SECTOR IN BC (1988)

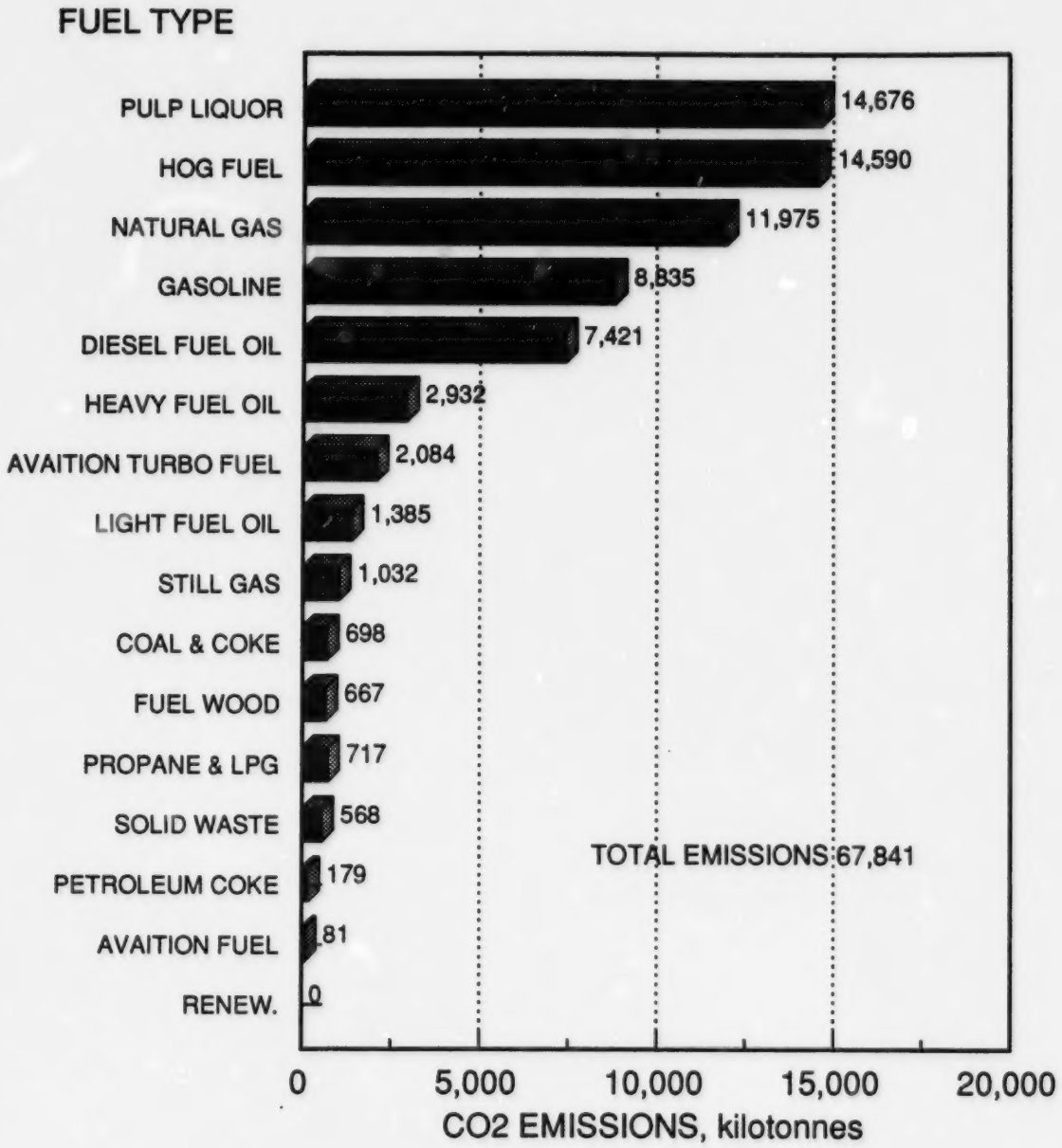


FIGURE III-8 CO2 EMISSIONS BY FUEL TYPE IN BC (1988)

estimates, averaging the remaining values and rounding up. These individual uncertainty estimates were propagated through the inventory to arrive at the standard uncertainty calculated by the equation:

$$\varepsilon_T = \frac{\sqrt{\sum_{i=1}^{n} (\varepsilon_i E_i)^2}}{E_T}$$

where:

ε_i = relative uncertainty in each emission estimate

ε_T = overall relative uncertainty

E_i = emission estimate for each category

E_T = overall emission estimate

By this method, the following relative uncertainties were determined and found to appear reasonable:

• Process sources	20%	3,239 ± 650
• Stationary combustion sources	25%	41,033 ± 10,300
• Mobile combustion sources	25%	17,412 ± 4,400
• Solid waste disposal sources	50%	9,396 ± 4,700
• Prescribed burning	75%	13,300 ± 10,000

The composite uncertainty in total CO_2 emissions in B.C. for 1988 was calculated to be 21% (84,380 ± 17,700).

B. CO_2 Uptake

1. Annual Uptake by Sector

(a) Forest Sector

Based on data from Bickerstaff et al. (1981), Hegyi et al. (1979) and Smith (1976), estimated annual uptake of carbon by forests in British Columbia is about 54,000 kt of carbon per year. The breakdown by species groups and by mature and immature forests is summarized in Table III-8.

TABLE III-8

Estimated annual accumulation of total bolewood plus bark, total above-ground biomass, and total above-ground carbon in immature and mature species groups in British Columbia.

(Sources: Smith 1976, Hegyi et al. 1979, Bickerstaff et al. 1981)

	IMMATURE FOREST		MATURE FOREST	
Species Group	Annual Growth (10^6 m^3)	Annual Biomass Increment Bolewood & bark (10^9 kg)	Annual Growth (10^6 m^3)	Annual Biomass Increment Bolewood & bark (10^9 kg)
Spruce	19.6	8.52	6.0	2.61
Pine	7.5	3.35	6.6	2.95
Fir	6.4	2.65	2.6	1.07
Hemlock	12.3	6.22	5.4	2.70
Douglas fir	3.0	1.78	1.4	0.84
Larch	0.2	0.15	0.06	0.04
Other conifer	2.3	0.85	3.4	1.27
Poplar	0.03	0.01	0.1	0.05
Birch	0.08	0.05	0.02	0.01
Aspen	3.1	1.35	1.2	0.53
Total bolewood & bark		24.9		12.1
Expansion factor		3.6		2.3
Total biomass (10^9 kg)		90.8		27.8
Total carbon (10^9 kg) *		41		13

* Conversion factor 0.45

By the methods used here, the annual growth of mature/ overmature forests in British Columbia is estimated to produce about 12,000 kt of biomass in merchantable bolewood plus bark. The total production in these forests, including nonmerchantable materials and submerchantable trees, probably reaches almost 28,000 kt of biomass which is equivalent to 13,000 kt of carbon. In immature forests, annual production is estimated at about 25,000 kt of merchantable wood plus bark, more than twice the amount in the mature/overmature forests.

Since there is more nonmerchantable biomass in immature stands than in mature stands, the expansion factor to include all new growth in the immature forests is higher than the factor used for mature forests. As indicated in Table III-8, using an expansion factor of 3.6, the total biomass in the immature forests is estimated to be about 41,000 kt in terms of carbon and the total for mature plus immature is 54,000 kt of carbon. The methods described in Appendix III indicate that there is considerable range in the choice of expansion factor to use. The examples derived from biomass increment data for Douglas fir and aspen suggest an expansion factor of about 1.5 instead of the 2.3 and 3.6 factors used here for mature and immature forests, respectively. If a 1.5 factor were applied, then total annual fixation in immature forests would be only 17,000 kt of carbon and in mature forests only 8,000 kt of carbon. This would represent a total of 25,000 kt of carbon captured each year by British Columbia's forests.

The present analysis did not include an estimate of the uptake of carbon in regeneration forests nor an estimate of carbon fixation in areas classified as unproductive forest lands. It was assumed that the uptake of carbon in the latter is probably very small. As in Comeau's analysis, this study does not give an estimate of carbon uptake by root production. It is known that the proportion of weight in roots decreases greatly as tree size increases, but there is little information on root production for different maturity classes of British Columbia forests. From one study in a mature lodgepole pine ecosystem, below-ground production represented approximately 40% of total net primary production (Comeau and Kimmins 1989). Since most of the fine roots die and decompose rapidly within the year they would not be a substantial carbon sink. However, medium and large roots are a carbon reservoir beyond the above-ground estimates listed in Table III-8.

(b) River Sector

Next to forests, the second most important carbon sink in British Columbia appears to be rivers, based on the methods of estimation used in this study. Table III-9 summarizes estimated carbon sinks in the main rivers of British Columbia. For the main rivers combined, annual

TABLE III-9

Estimated total organic carbon export from the main rivers in British Columbia. See Section II B for explanation of methods, assumptions and data sources.

(1) River	(2) Mean annual discharge ($m^3\ s^{-1}$)	(3) Annual TOC load (10^6 kg)	(4) Dry season TOC conc. (g C m^{-3})	Estimated annual TOC export (10^6 kg)	
B.C. Mainland				col (3) x 0.25	col (3) x 0.6
Fraser	3620	827.0	1.5-3.7	207	496
Skeena	1760	402.1		101	241
Stikine **	1080	246.7		62	148
Nass **	892	203.8		51	122
Kitimat	134	30.6		8	18
Bella Coola	95	21.7		5	13
Squamish	250	57.1	3.5	14	34
				col (3) x 0.25	col (3) x 0.25
Columbia **	2890	660.0		165	165
Peace **	1400	319.8		80	80
Liard **	1300	297.0		74	74
Taku **	250	57.1		14	14
Van. Island				col (3) x 0.50	col (3) x 0.6
Nimpkish	129	29.5		15	18
Somass	126	28.8		14	17
Campbell	99	22.6	3.0-6.0	11	14
Gold	88	20.1		10	12
Salmon	66	15.1		8	9
Courtenay	57	13.0		7	8
Cowichan	53	12.1	3.0	6	7
Nanaimo	41	9.4	3.0-3.5	5	6
Chemainus	19	4.3		2	3
Oyster	15	3.4		2	2
Koksilah	10	2.3		1	1
Quinsam	9	2.1		1	1
TOTAL EXPORTED TOC				862	1505
80% OF EXPORTED TOC DEPOSITED IN COASTAL SEDIMENT				690	1204

* TOC = total organic carbon

** Estimate of carbon sink is for only the portion of the river occurring within British Columbia

export of total organic carbon is estimated to range from 690 to 1204 kt C yr^{-1}. This estimate is based on the assumption that the concentration of total organic carbon sampled in the dry season represents the level of carbon generated within the river's photosynthetic system and excludes river-borne carbon derived from land ecosystems. Because the analysis excluded the many small rivers in British Columbia, the figures shown in Table III-9 may be an underestimate.

(c) Wetland Sector

A recent estimate indicates that wetlands in British Columbia occupy about 31.2 x 10^3 km^2 (Environment Canada 1986). In the interior, the area of organic wetlands is estimated to be 9.32 x 10^3 km^2 (British Columbia Ministry of Agriculture and Food 1981; Whillans 1987). This review did not reveal specific British Columbia data on accumulation rates for peat in these wetlands. However, studies in other regions indicate a range from 7 g C m^{-2} yr^{-1} in arctic Alaska to a high of about 70 g C m^{-2} yr^{-1} in northern Wisconsin (Schell and Ziemann 1983, Kratz and deWitt 1986). The accumulation rate for European peatlands is about 20-40 g C m^{-2} yr^{-1} (Mitsch and Gosselink 1986). The latter range is assumed to be applicable for organic wetlands in B.C. On this basis, an estimated 186 to 373 kt C m^{-2} yr^{-1} are probably stored in the organic wetlands of interior B.C. No quantitative data were available for estimation of annual carbon accumulation rates in blanket bogs that characterize certain ecosystems in north coastal British Columbia.

Estuarine wetlands are usually ecosystems of high primary productivity. There have been several studies on the primary production of tidal marshes on the deltaic deposits of Fraser River. The estimated annual production is in the range of 290 to 344 g C m^{-2} yr^{-1} (Kistritz and Yesaki 1979). A higher productivity of 595 g C m^{-2} yr^{-1} was recorded for the tidal marshes at Squamish River. An estimated 60% of the annual production from the tidal marshes in the Fraser River is lost to the ocean. Most of this organic matter would be deposited as sediment on the continental shelf.

The area of wetlands in the southwest Fraser Lowland is estimated to be 235 km^2 (Pilon and Kerr 1984). If one assumes that the estimates for primary productivity and the 60% loss to sea are applicable to this area, then the potential sink of carbon is about 41 to 48 kt C yr^{-1}.

Of the total wetland area in British Columbia, another 21.6 x 10^3 km^2 are not accounted for in the estimate shown in Table III-10. This area would include some peatlands in the Prince Rupert Forest Region and on Vancouver Island, as well as areas of estuarine wetlands along British Columbia's rivers other than the Fraser. Lacking sufficient

TABLE III-10

Estimated annual accumulation of carbon in British Columbia wetlands and in tidal marshes of the Fraser River.

Area of B.C. wetlands (marshes, bogs, swamps, fens)

Estimated total area, 3120×10^3 ha		(ref 1)
interior organic wetlands	932×10^3 ha	(ref 2)
S.W. Fraser River lowland	23.5×10^3 ha	(ref 2)

(i) Assume peat accumulation in organic wetlands of 20 - 40 g C m^{-2} yr^{-1}. Thus, for interior B.C., the total is 186 - 373 $\times 10^6$ kg C yr^{-1}

(ii) Fraser River tidal marshes

primary production	290 - 344 g C m^{-2} yr^{-1}	(ref 3)
60% loss annually (to ocean)	174 - 206 g C m^{-2} yr^{-1}	(ref 3)
80% deposited in coastal sediment	139 - 165 g C m^{-2} yr^{-1}	(ref 4)
total loss as sink	33 - 39 $\times 10^6$ kg C yr^{-1}	

(iii) Total for (i) and (ii) 219 - 412 $\times 10^6$ kg C yr^{-1}

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1. Environment Canada (1986)

2. Whillans (1987)

3. Kistritz and Yesaki (1979)

4. Garrels and Mackenzie (1981)

information on these wetlands, it was not possible to estimate the annual carbon uptake of these areas.

By the methods used in these analyses, wetlands and tidal marshes appear to be the third most important CO_2 sink in British Columbia. As summarized in Table III-10, annual fixation of carbon in these ecosystems is estimated to range from 219 to 412 kt C yr^{-1}. The figures given may be underestimates because smaller tidal marshes in the province are excluded. Also there is a substantial, but unquantified, amount of carbon stored in the peaty surface layer that underlies relatively large areas of forest overstorey in the north coastal region of British Columbia (Banner et al. 1986).

(d) Lakes Sector

Lakes in British Columbia cover a total area of about 16,356 km^2 (Northcote and Larkin 1966). This area estimate does not include the increase in area caused by impoundment of rivers. Using a sedimentation rate of 6.5 to 12.0 g C m^{-2} yr^{-1}, the total amount of carbon buried annually as lake sediment is estimated to be 106 to 196 kt C yr^{-1} (Table III-11). The estimates are based mainly on data from one coastal study site, Marion Lake on the University of British Columbia Research Forest. Extrapolation of carbon fixation data from that one lake to all of the freshwater surface area in the province may result in a substantial overestimate or underestimate.

(e) Summary of Main Sectors as CO_2 Sinks

Potential CO_2 sinks in British Columbia's ecosystems can be summarized as follows:

1. Forests	54,000 kt C/yr *
2. Rivers	690 to 1204 kt C/yr
3. Wetlands	219 to 412 kt C/yr
4. Lakes	106 to 196 kt C/yr

* compared to 53,000 kt C/yr estimated by Comeau (in prep A).

2. Error of Estimates

Most of the carbon uptakes estimated in this report depend ultimately on the photosynthesis of various plant species in terrestrial or aquatic ecosystems. It is known that quantitative estimates based on ecosystem parameters such as net primary productivity and decomposition rates are highly variable. For this reason it is not possible to provide a statistical analysis of the error associated with each of the estimates given in this report. The error discussed

TABLE III-11

Estimated annual accumulation of carbon in British Columbia lakes.

Area of Lakes in British Columbia

22 large lakes with area > 100 m^2	5998.6 km^2	(ref 1)
all lakes	16356 km^2	(ref 2)

C budget computation using results from Marion Lake (ref 3)

1. Method 1 (ref 4):

   Sedimentation rate = 8.0 g C m^{-2} yr^{-1}
   Extrapolation to all lakes = 131 x 10^6 kg C yr^{-1}

2. Method 2 (ref 4):

   Sediment accumulation ≈ 10 - 15% of net primary production
   primary production in B.C. lakes = 65 - 80 g m^{-2} yr^{-1}
   sedimentation rate = 6.5 - 12 g m^{-2} yr^{-1}
   extrapolation to all lakes = 106 - 196 x 10^6 kg C yr^{-1}

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1. Department of Environment (1973)

2. Northcote and Larkin (1966)

3. Richey et al. (1978)

4. Mulholland and Elwood (1982)

in the following paragraphs is used in the sense that the true values are expected to differ from the estimates by the given percentage. The percentage values should only be taken as a guide to the quality of the estimated CO_2 uptake values.

(a) Forest Sector

There was an inherent error of ± 5% for both area and volume values derived from Bickerstaff et al. (1981). The error for the average tree height used in the computation was probably ± 10%. If all errors were propagated through the computation, the absolute area for either immature or mature/overmature could have an error of ± 20%. Bonnor (1985) suggested that his biomass estimate may have an error of ± 5%. This latter percentage coupled with the error for expansion factor (± 10%) and the error for the carbon:biomass ratio (± 10%) could result in an error as great as ± 40% for the estimate of CO_2 uptake in forests.

The largest potential error in the estimated CO_2 sink for the forest sector is related to the choice of expansion factor to convert stem biomass increment to total above-ground increment. Appendix III-2 describes how expansion factors of 2.3 and 3.6 were derived for mature and immature forests, respectively. Alternative expansion factors, lower than the 2.3 and 3.6 used here, were summarized from the literature and are described at the end of Appendix III-2.

(b) River Sector

The quantity of riverflow depends very much on precipitation and therefore exhibits high seasonal variability. An educated guess for the error in mean annual discharge of river would be ± 10%. Chemical analysis of TOC is well established and the quality of the TOC data is expected to be relatively good. However, the variation of the TOC values is about ± 40%.

The final estimates for annual TOC export could vary within a range of ± 30%. These TOC export values are likely to be underestimates, since many of the minor rivers in B.C. were not included in the analysis.

(c) Wetlands Sector

The errors associated with the wetland estimates are considered to be substantial. For peat accumulation rates, the error is at least ± 30%. A slightly higher error (± 35%) might be attached to the figures for primary production in tidal marshes. As mentioned earlier, the values for carbon sinks in peatlands and tidal marshes are likely to be underestimates. If the estimates in this report were prorated to the total

wetland area in B.C., the carbon uptake from wetlands could be 3-1/2 times the value given in this report.

(d) Lakes Sector

Estimate of geographic area, which in this case is the area of lakes, is usually of good quality. For estimates of primary productivity in aquatic ecosystems, the error is estimated to be about ± 30%. The error for the sedimentation rate given in this report is about ± 33%. Thus, the final estimates of carbon uptake in freshwater ecosystems could have an error of ± 60%.

The composite uncertainty (as described in Section III.A.3.) in total CO_2 sinks in B.C. for 1988 was calculated to be 39% (55,414 ± 22,080).

Forests	± 40%	54,000	±	21,600
Rivers	± 30%	947	±	280
Wetlands	± 35%	316	±	110
Lakes	± 60%	151	±	90

C. Net CO_2 Emissions

Calculating net CO_2 emissions could be accomplished by summing all CO_2 emissions and CO_2 sinks and taking the difference. Unfortunately, this study only includes anthropogenic sources and wildfires and has omitted decomposition and human and animal respiration as sources. Oceans and some other natural sinks were also omitted. Under these conditions, the difference between incomplete summations of CO_2 emissions and sinks would be misleading.

Although CO_2 release from soil respiration is relatively simple to measure for a given time interval at a specific location in the field, it is extremely difficult to obtain reliable estimates that integrate this source of CO_2 over time for different ecosystems in a region. There are global estimates of biological sources of CO_2 and, lacking specific data for British Columbia, one approach is to apply to this region the global ratio between photosynthetic fixation of CO_2 and soil respiratory release of CO_2. One estimate of total photosynthetic carbon fixation by land plants is 120×10^9 tyr^{-1}. However, the earth's vegetation respires 56×10^9 t of C per year, leaving a net gain of 64×10^9 t of C per year. Annual worldwide addition of plant material to the pool of dead organic matter (in litter and soil) is estimated to be 45×10^9 t of C per year by direct addition of dead plant material and another 1×10^9 t of C per year by plant material that becomes dead organic matter after passing through animals. The pool of dead organic matter releases an estimated 58×10^9 t of C per year as a result of

soil respiration (Kimmins 1987, based on Bolin et al. 1979 and Clark et al. 1982). The earth's average ratio of 64:58, representing the relationship between carbon fixed by land plants annually and carbon respired annually from the earth's sink of dead organic matter, can be used as a crude estimate of annual carbon release from soil respiration in British Columbia's portion of the earth's surface. If this ratio (1:.91) is applied to the estimated net annual fixation of 54,000 kt C by forests in British Columbia (Table III-9), respiratory release of carbon from forest floor litter and soil organic matter could be as great as 54,000 x .91 = 49,000 kt C per year.

An uncertainty with the above approach is that the global average may be very different than that typical of British Columbia's forest ecosystems. For example, reports by Graham and Cromack (1982), Sollins (1982), Harmon et al. (1986) and Alaback (1989) have made the point that for old growth forests in the Pacific Northwest carbon is cycled quickly for some components such as fine litter but very slowly for the large pools of coarse woody debris and soil organic carbon. On the Olympic Peninsula, a 37 cm western hemlock and a 54 cm Sitka spruce were estimated to require up to 280 years to completely decompose. If large downed trees become buried in soil their residence times may exceed 1,000 years, making them very long-term sinks (Alaback 1989).

There are insufficient data to obtain a provincial estimate of accelerated carbon release as a result of forest harvesting. In a variety of temperate forest studies summarized by Alaback (1989), from 25 to 60% of soil carbon is lost following logging. Following harvesting, the greatest acceleration of carbon loss occurs in the warmest climates and on well-drained sites (Schlesinger 1977). In the cool, wet climate of southeast Alaska, Alaback (1989) predicted that poorly drained sites would experience the least acceleration of carbon release after harvest. However, studies elsewhere (Vitousek 1983) have shown that in virtually all forest types, including poorly drained ones, the harvesting of old-growth forest and its replacement with managed second growth results in an overall net emission of soil carbon to the atmosphere. Alaback's call for research on how regeneration, tree growth and carbon cycling vary across a range of soil and microclimatic conditions applied as much to British Columbia as it does to southeast Alaska.

The estimated annual release of 49,000 kt of carbon from dead organic matter is substantially lower than the estimate of 109,200 kt of carbon released by annual decomposition in Alberta (Wiggins and Yurko 1989). The estimate that decomposition annually releases about 90% as much carbon per year as is fixed by land plants is considered to be a reasonable one for British Columbia.

Release of CO_2 from agricultural lands, wetlands and other kinds of non-forested lands is as difficult to estimate on a regional basis, as it is for forest litter and forest soils. For agricultural ecosystems it is assumed that, except for a small amount of biomass that can accumulate in the roots of perennial agricultural crops, annual decomposition release of CO_2 is assumed to be equal to annual fixation of CO_2 by photosynthesis. The same is assumed for herbaceous non-forested ecosystems and

most wetlands. It is known that there can be a net accumulation of carbon in peatlands and in shrubby non-forested ecosystems. However, lacking data for British Columbia, the present analysis assumed that these ecosystems, too, were more or less in equilibrium as far as annual CO_2 gain and CO_2 release is concerned.

Some of the CO_2 released from soil respiration is 'short- cycled' directly back into photosynthetic uptake without mixing with other atmospheric CO_2 (Kimmins 1987). This is more true for forests than for agricultural ecosystems; the deeper canopy of forest cover provides an opportunity for calm air to persist, whereas in agricultural vegetation cover CO_2 released from soil decomposition is more readily mixed with air layers above the canopy. It has been estimated by Hellmers (1964) that the enhanced morning photosynthesis that results from the retention of respiratory CO_2 within the forest canopy could account for an increase of up to 2.5% in the canopy's photosynthetic efficiency. This phenomenon indicates why decomposition must be an integral part of any attempts to estimate CO_2 exchanges between the atmosphere and vegetation. When compiling CO_2 budgets it is not correct to assume that a given amount of carbon accumulated in forest biomass has been all withdrawn from regional air masses. There are no data to indicate how much of the CO_2 taken up by British Columbia's forests is a result of morning photosynthetic absorption of CO_2 that has been released on the growing site by night-time decomposition of dead organic matter.

IV. METHODOLOGY USED FOR CO_2 EMISSIONS FORECAST

A. CO_2 Sources

1. General

Much of the forecast of CO_2 emissions was based on the EMPR forecasts of energy demand, taken from their "B.C. Energy Supply and Requirements Forecast 1984-2005" (1986). The general EMPR forecast methodology is described below. Details of the methodologies are described in the individual sector and subsectors. Industry forecasts were also used especially in the non-combustion source sectors.

EMPR uses an econometric model to forecast future energy demand in B.C. The model first projects sector energy consumption, and then disaggregates this total to the various fuels according to market shares, subject to a variety of constraints and energy consumption relationships. In this way, econometric models are the same. Energy, Mines and Resources' (EMR), Interfuel Substitution and Demand (IFSD) model is another example of an econometric model. The output from the IFSD model was used as a comparison to the EMPR forecasts.

Forecasts made using an econometric model are based on world oil prices. Domestic energy prices are derived from the world oil price forecast. Obviously, variations in world oil price forecasts or derived domestic energy forecasts will affect the projections of energy consumption.

Forecasts of economic growth, population growth, interest rates, etc., are used to "drive" econometric models. "Driving" refers to effects that the above variables have on energy consumption patterns. For example, increased population results in increased energy consumption. Slower economic growth or higher interest rates tend to restrict energy consumption.

Econometric models employ a variety of relationships in the modelling process. These include relationships between energy consumption and energy price, alternative fuels, the lag time between changes in energy price and changes in fuel choice, etc. The EMPR have statistically derived many of these relationships or equations from historical data. New data is continually being incorporated to update the relationships employed in the model. Consequently, EMPR's updated version of the "Energy Supply Requirements Forecast" to be released in March, 1990 should provide improved forecasts for 2005 than the 1986 version used here.

According to EMPR (Bell, 1990) the two versions of the model do not differ dramatically in the energy consumption forecasts. There may be considerable differences in individual sectors, however. A more complete description of the EMPR's model is available from the Forecasts and Special Projects Branch of the EMPR.

A summary of the overall growth rates applied to each sector and subsector to arrive at the forecast CO_2 emissions appears in Table IV-1. Detailed descriptions by sector and subsector are in Appendix V. The reported value is the percentage growth over the period from 1988 to 2005. Note that this applies only to the sector or subsector overall energy requirements and CO_2 emissions, not to individual fuel requirements within the sector or subsector.

Typical growth values over the period from 1988 to 2005 ranged from 4% to 64%. A few sectors grew even more because of major changes in energy usage in these sectors. Natural gas road vehicles, thermal power generation, mining and primary metal production are examples of this. Overall decreases in CO_2 emissions were forecast for petroleum refining, other manufacturing, landfill gas, wood waste incineration and prescribed burning.

B. CO_2 Uptake

There is no firm basis from which to predict whether British Columbia's ecosystems will be greater or lesser CO_2 sinks in 2005 than they are now. If, as Schneider (1989) suggests, global warming should be unmistakable within a decade or two, one could hypothesize that there could be greater photosynthetic rates. However, warmer temperatures could result in greater decomposition rates of organic materials, partially offsetting the potentially higher photosynthetic rates. These possible changes could also interact with other aspects of growth, such as water-use efficiency. It is now known that elevated CO_2 can lessen the effects of water stress. For example, the percentage increase in biomass accumulation following a period of drought is larger in elevated CO_2 than in ambient CO_2 (Eamus and Jarvis 1989). The latter authors stressed that at a regional scale there is a very complex network of processes to take into account and that "there is quite insufficient information about effects of CO_2 on these processes to permit reasonable predictions".

Certain silvicultural practices such as fertilization or removal of competing vegetation can substantially increase annual growth of forest stands. Here, too, it would be very speculative to suggest what effect such practices could have on carbon accumulation rates in forests during the next 15 years. In any case, intensive silvicultural practices such as these are themselves consumers of energy and emitters of CO_2.

TABLE IV-1 SUMMARY OF GROWTH RATES BY SOURCE SECTOR

Source Sector/Subsector	Percentage Change Between 1988 and 2005	
	Energy Consumption (%)	CO_2 Emissions (%)
Process Sources		
Lime Kilns		89
Cement Kilns		35
Pulp and Paper Kilns		12
Methanol/Ammonia		45
Chemical Industries		45
Aluminum Smelting		0
CO Boilers (Petroleum Refining)		(36)
CO_2 Stripped from Natural Gas		23
Total Process		16
Stationary Combustion Sources		
Gas Utilities	23	23
Power Generation	448	434
Residential/Agricultural	46	53
Commercial/Public Administration	69	64
Industrial		
Pulp and Paper	11	9
Wood Products	(2)	4
Primary Metals	117	118
Chemical Industry	16	13
Non-Metallic Minerals	304	456
Petroleum Refining	(42)	(46)
Other Manufacturing	(19)	(27)
Mining	104	122
Other Industrial	39	71
Total Industrial	16	16

TABLE IV-1 SUMMARY OF GROWTH RATES BY SOURCE SECTOR (CONTINUED)

Source Sector/Subsector	Percentage Change Between 1988 and 2005	
	Energy Consumption (%)	CO_2 Emissions (%)
Stationary Combustion Sources (continued)		
Fuel Wood	0	0
Total Stationary	37	35
Mobile Combustion Sources		
Road		
Gasoline	35	35
Diesel	46	46
Natural Gas	541	541
LPG	(6)	(6)
Total Road	38	38
Rail	11	11
Marine	17	17
Air	21	21
Off-Road	35	35
Total Mobile	31	31
Solid Waste Disposal		
Municipal Incineration		85
Landfill Gas		(38)
Industrial and Institutional Incineration		25
Wood Waste Incineration		(25)
Total Solid Waste		(22)
Prescribed Burning		(30)

For reasons outlined above, the CO_2 forecasts of this report are based on the assumption that British Columbia's forests will have approximately the same annual rates of CO_2 fixation in 2005 as they have now.

The same arguments would apply to wetlands and other aquatic ecosystems in which slightly higher photosynthetic rates enhanced by higher CO_2 levels and higher temperatures would be offset by increases in plant respiration. With a possibly warmer climate, decomposition of organic carbon in soils and river sediments would accelerate, and consequently there could be a slower rate of peat accumulation in various wetland ecosystems. Though the increase in carbon uptake might not be balanced by the concomitant increase in carbon releases, any difference in the carbon balance would likely be small.

V. FORECAST OF CO_2 EMISSIONS AND UPTAKE FOR 2005

A. CO_2 Emissions

1. Annual Emissions by Source Sector

Total anthropogenic CO_2 emissions are forecast to increase from 84,380 kt CO_2 in 1988 to 98,708 kt CO_2 in 2005 (Figure V-1). This is a 17% increase in emissions, which is within the uncertainty of the estimates (21%). The main reason for the moderate increase in CO_2 emissions is a projected decrease in prescribed burning of 4,000 kt CO_2. Wood waste incineration is also projected to decrease by 2,200 kt CO_2. These two decreases amount to 7% of the 1988 CO_2 emissions.

CO_2 emissions for all source sectors and subsectors, by order of rank are reported in Figure V-2. The top five sources account for 63% of the total anthropogenic CO_2 emissions in 2005. These are the same five sources which were on the top of the list in 1988. In 2005, because of reductions in CO_2 emissions from prescribed burning and wood waste incineration and because of increases in CO_2 emissions from road vehicles and residential/agricultural sectors, the latter two sectors move up to second and fourth largest emitters, respectively. The former two sectors fall to third and fifth largest emitters, respectively.

Stationary combustion sources remain the largest anthropogenic emitters of CO_2 according to the forecast. The 55,530 kt CO_2 from these sources account for 56% of the total 2005 CO_2 emissions. Mobile combustion and solid waste disposal are expected to account for 23% and 7%, respectively. Prescribed burning sources are projected to decrease to 9% of the total. Process sources should remain as very minor contributors, accounting for less than 4% of CO_2 emissions in 2005.

A partial comparison was possible using Energy, Mines and Resources' (EMR) "Vision 2020, Energy Supply and Demand Forecast for B.C., and the Yukon and Northwest Territories". Emissions for the source sectors where energy consumption data was available were calculated and compared to this inventory in Table V-1. The major differences between the inventories lies in the industrial sector and transportation source CO_2 emission estimates.

The partial inventories differed by only 8,800 kt CO_2 or about 13%. About 5,500 kt CO_2 and 2,600 kt CO_2 in the industrial sector and mobile combustion sources group respectively, account for over 90% of the difference.

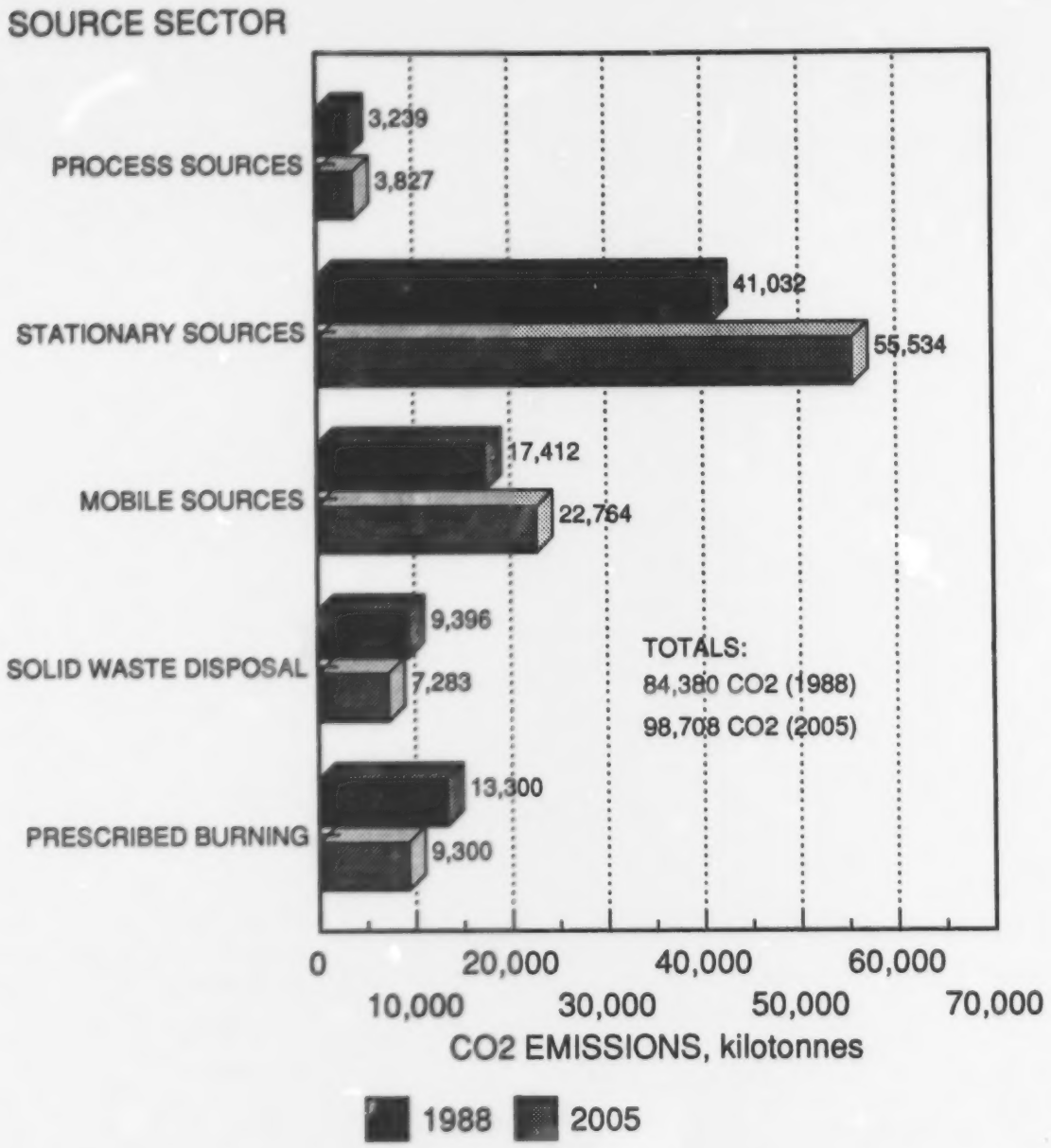


FIGURE V-1 COMPARISON OF 1988 & 2005 CO2 EMISSIONS BY MAJOR SOURCE SECTORS IN BC

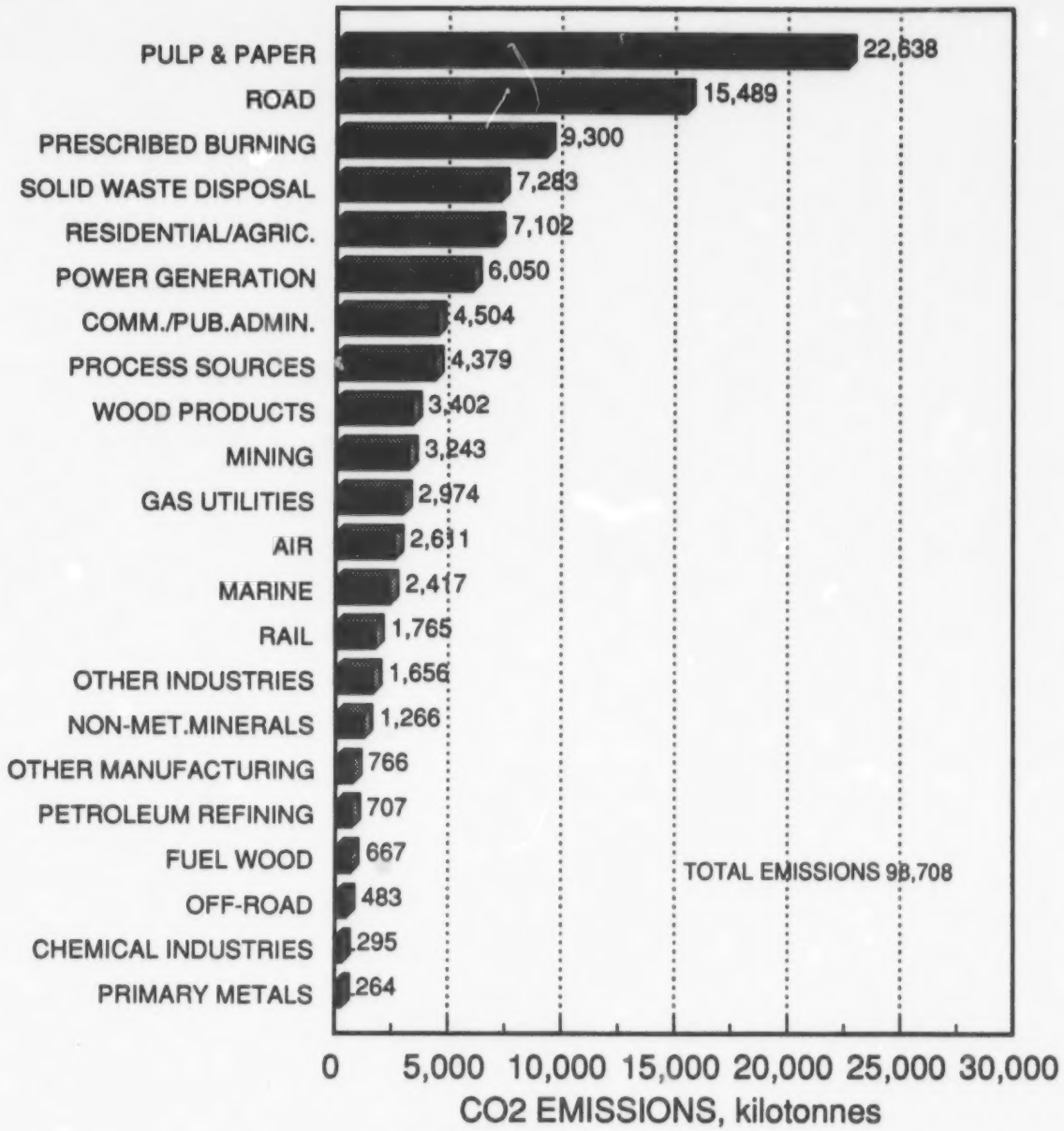


FIGURE V-2 CO2 EMISSIONS BY SOURCE SECTOR IN BC (2005)

TABLE V-1 PARTIAL COMPARISON USING EMPR & EMR ENERGY CONSUMPTION VALUES FOR 2005

kilotonnes CO2

	EMPR	EMR
RESIDENTIAL/AGRIC.	7,102	5,489
COMM./PUB. ADMIN.	4,504	5,508
INDUSTRIAL	34,237	28,560
ROAD	15,489	14,046
RAIL	1,765	1,261
MARINE	2,417	2,126
AVAITION	2,611	2,450
OFF-ROAD	483	
TOTAL	68,608	59,440

The partial EMPR and EMR inventories grew by 26% each. This confirms that the assumptions in the EMPR model and in EMR's IFSD model are very similar.

(a) Process Sources

Process sources remained as relatively insignificant emitters of CO_2. Their contribution increased slightly from 3.8% to 3.9% of the total CO_2 emissions. Only 3,827 kt CO_2 would be emitted from process sources according to the forecast.

(b) Stationary Combustion Sources

Stationary combustion sources are expected to emit 55,530 kt CO_2 in 2005. This is 56% of the total, up from 49% in 1988. The CO_2 emissions from the six sectors are reported in Table V-2 and shown in Figure V-3.

Industrial source CO_2 emissions are expected to remain the largest sector by far, emitting 34,240 kt CO_2. This is nearly 62% of the stationary combustion source CO_2 emissions, down from 72% in 1988. CO_2 emissions from the nine industrial subsectors are reported in Table V-3 and shown in Figure V-4.

Residential/agricultural and commercial/public administration CO_2 emissions accounted for 13% and 8%, respectively. This is an increase from 11% and 7% in 1988 for the two subsectors.

(c) Mobile Combustion Sources

Mobile combustion sources are projected to remain the second largest emitter of CO_2 emissions in 2005. The 22,760 kt CO_2 forecast, accounts for 23% of the total anthropogenic CO_2 emissions. This is up from 21% of the total in 1988. Emissions are reported in Table V-4 and shown in Figure V-5. Increased road vehicle CO_2 emissions and decreased CO_2 emissions from solid waste disposal and miscellaneous sources causes the mobile source sector to rise from third rank in 1988 to second rank in 2005.

Road vehicles, omitting natural gas and propane, are expected to account for 66% of the mobile combustion source emissions in 2005. This is up from 63% in 1988. Air, marine and rail sectors account for 12%, 11% and 8% of the mobile source CO_2 emissions. These are down slightly from 1988.

TABLE V-2 STATIONARY COMBUSTION SOURCES OF CO2 EMISSIONS IN BC (2005)

	kilotonnes CO2
GAS UTILITIES	2,974
POWER	6,050
RESIDENTIAL/AGRIC.	7,102
COMM./PUB.ADMIN	4,504
INDUSTRIAL	34,237
FUEL WOOD	667
TOTAL	55,534

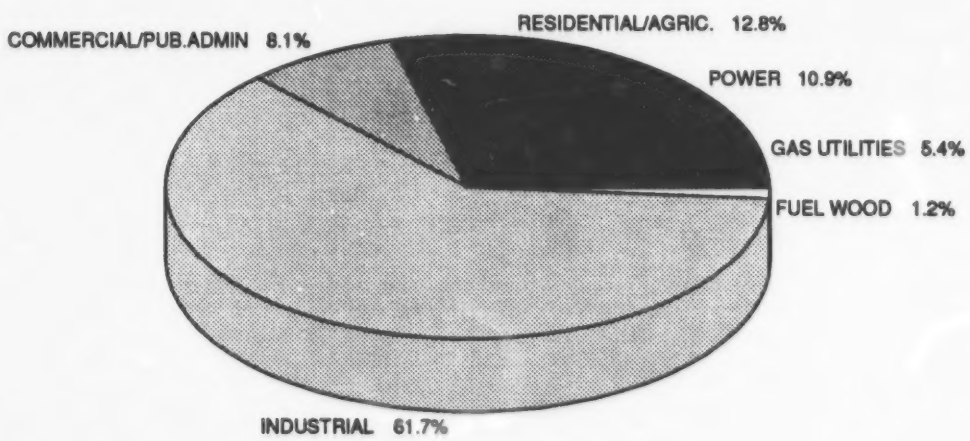
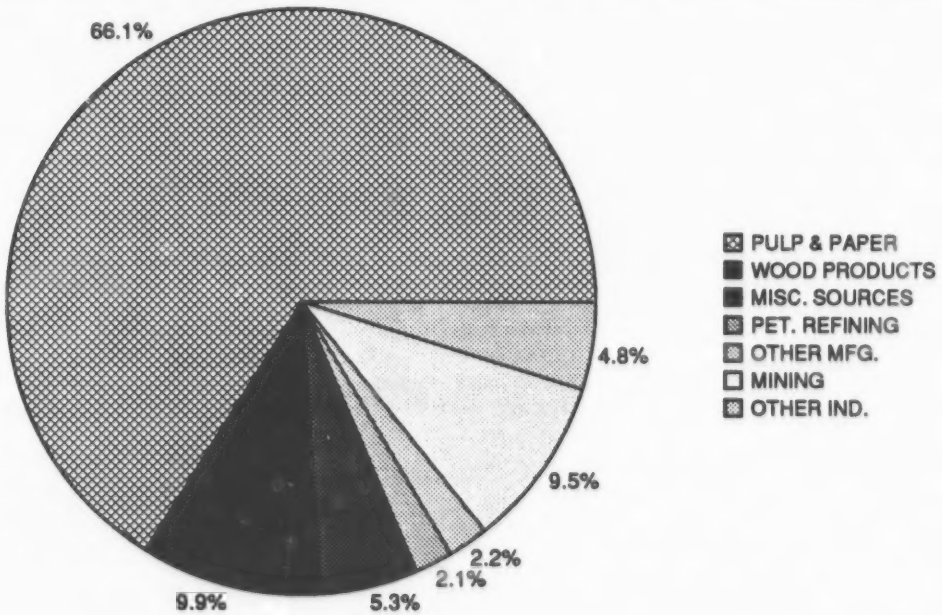


FIGURE V-3 STATIONARY COMBUSTION SOURCES OF CO2 EMISSIONS IN BC (2005)

TABLE V-3 INDUSTRIAL SECTOR CO2 EMISSIONS IN BC (2005)

	kilotonnes CO2
PULP & PAPER	22,638
WOOD PRODUCTS	3,402
MISC. SOURCES	1,825
PET. REFINING	707
OTHER MFG.	766
MINING	3,243
OTHER IND.	1,656
TOTAL	34,237



MISC. SOURCES: INCLUDES PRIMARY METALS, CHEMICAL, & NON-METALLIC INDUSTRIES

FIGURE V-4 INDUSTRIAL SECTOR CO2 EMISSIONS IN BC (2005)

TABLE V-4 MOBILE COMBUSTION SOURCES OF C02 EMISSIONS IN BC (2005)

	kilotonnes CO2
ROAD	14,937
RAIL	1,765
MARINE	2,417
NATURAL GAS / LPG	551
AIR	2,611
OFF-ROAD	483
TOTAL	22,764

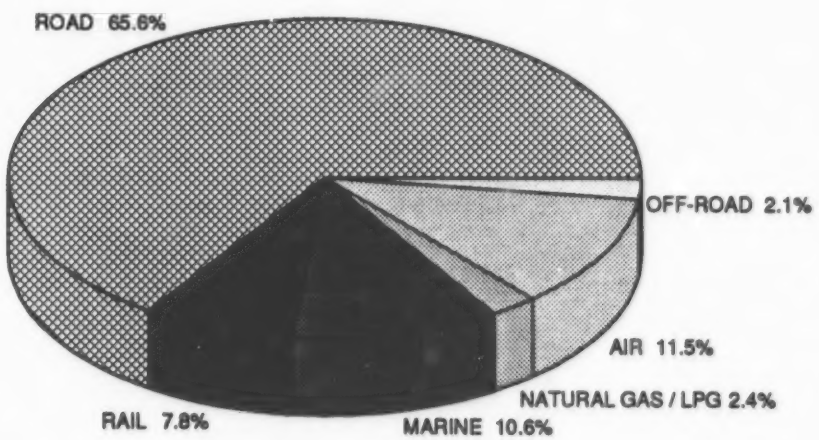


FIGURE V-5 MOBILE COMBUSTION SOURCES OF CO2 EMISSIONS IN BC (2005)

(d) Solid Waste Disposal

Solid waste disposal in B.C. is expected to decrease to 7,283 kt CO_2 in 2005. This is a decrease of 2,113 kt from the 1988 estimate of 9,396 kt CO_2. A projected decrease in wood waste (hog fuel) incineration results in the estimated decrease in CO_2 emissions from this sector. CO_2 emissions from this sector are given in Table V-5 and Figure V-6.

(e) Prescribed Burning

Prescribed burning is expected to decrease by approximately 30% by 2005. As a result of this forecast, the share of total CO_2 emissions associated with prescribed burning will drop from 16% in 1988 to 9% in 2005.

2. Annual CO_2 Emissions by Fuel Type

Fuel combustion is projected to emit 82,310 kt CO_2, or 83% of the total CO_2 emissions in B.C. for 2005. This is up from 80% in 1988. The remaining 16,400 kt CO_2 are projected to be emitted from process sources and prescribed burning. The top five fuel types account for 84% of the total CO_2 emissions from fuel combustion (Figure V-7). Hog fuel and pulping liquors account for 36% of the CO_2 emissions from fuel combustion in 2005. This is down from 43% in 1988. Natural gas is projected to become the largest fuel type emitter, accounting for 20% of CO_2 emissions from fuel combustion. Motor gasoline and diesel fuel are expected to account for 15% and 14%, respectively.

Fossil fuels are projected to account for 51% of the total CO_2 emissions in 2005, up from 44% in 1988. Fossil fuels are expected to account for 62% of the CO_2 emissions from fuel combustion only, up from 55% in 1988. Biomass accounts for almost 16% of total, and 19% of fuel combustion CO_2 emissions in 2005. This is down from 17% and 23% respectively. Coal is expected to account for 2.0% of total, and 2.5% of fuel combustion CO_2 emissions in 2005. This is about double its share in 1988.

B. Net CO_2 Uptake

There is no firm basis from which to predict whether British Columbia's ecosystems will be greater or lesser CO_2 sinks in 2005 than they are now. Consequently, the 2005 CO_2 sinks are assumed to be approximately equal to the 1988 estimates.

TABLE V-5 SOLID WASTE DISPOSAL SOURCES OF CO2 EMISSIONS IN BC (2005)

	kilotonnes CO2
MUNICIPAL INCINER.	451
INDUSTRIAL INCINER.	18
LANDFILLS	194
WOOD WASTE	6,621
TOTAL	7,283

MUNICIPAL INCINERATION INCLUDES:
6.0% MUNICIPAL AND 0.2% INDUSTRIAL INCINERATION

FIGURE V-6 SOLID WASTE DISPOSAL SOURCES OF CO2 EMISSIONS IN BC (2005)

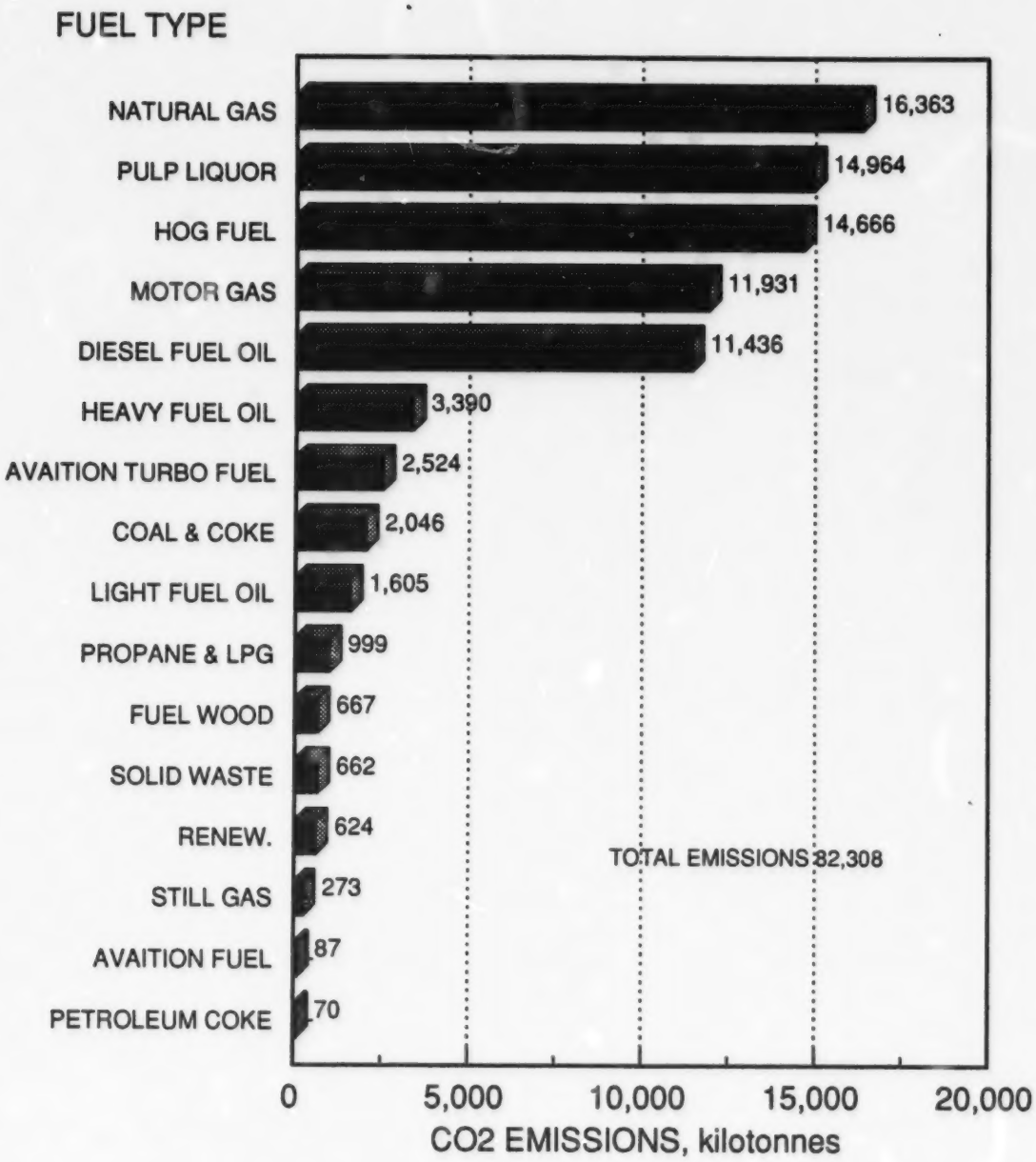


FIGURE V-7 CO2 EMISSIONS BY FUEL TYPE IN BC (2005)

C. Net CO_2 Emissions

Growth in CO_2 emissions of 17% between 1988 and 2005 is comparable to the estimated 21% uncertainty in the inventory estimates. Assuming changes in sinks are relatively small, it seems reasonable that net CO_2 emissions in 2005 will remain close to the 1988 level, within the range of estimated uncertainty.

VI. POTENTIAL CO_2 REDUCTION OPPORTUNITIES

A. Opportunities

The intent was to generate a master list of reduction opportunities to serve as a basis for further studies and discussions. It was beyond the scope of work to evaluate the various opportunities in any detail. A qualitative discussion of reduction potential, state of development, advantages and disadvantages and relative attractiveness of the opportunities has been included in an attempt to focus attention on some of the more promising possibilities.

There are a variety of opportunities for reducing the net emissions of CO_2 to the atmosphere. The following approaches are suggested as some ways in which reductions in CO_2 could be achieved:

1. Reduce energy consumption, in particular fossil fuels.

2. Increase the efficiency of fossil fuel utilization to decrease the amount of fuel required per unit energy output.

3. Increase the use of energy sources which do not emit CO_2 (eg., hydro, nuclear).

4. Increase the use of fuels which emit less CO_2 per unit energy output.

5. Capture the CO_2 emitted during combustion of fuels and store it indefinitely.

6. Reduce or capture the CO_2 emitted during producing, processing and transporting of fuels.

7. Reduce the emissions of CO_2 from sources not involving fuel combustion (ie., process sources).

The above methods cover essentially all the general oportunities available for reducing net CO_2 emissions. For practical purposes, a master list of obvious CO_2 reduction measures, as reported in Table VI-1, was organized by the same sector and subsector breakdown used in the CO_2 emissions inventory. This facilitates relating specific measures to individual source sectors and subsectors. The 1988 CO_2 emissions, in percent, and the potential CO_2 reduction measures are listed in Table VI-1 for each of the sectors and subsectors in the Inventory. An approximate rating of the CO_2 reduction potential and state of development is also included in the Table.

TABLE VI-1 CARBON DIOXIDE REDUCTION OPPORTUNITIES

SECTOR/SUB-SECTOR	1988 EMISSION (%)	CO2 REDUCTION METHOD	CO2 REDUCTION POTENTIAL	STATE OF DEVELOPMENT
PROCESS SOURCES				
LIME KILNS	0.2	CAPTURE CO2	L	U
		USE ALTERNATE MATERIALS TO REDUCE LIME USE	L	P
CEMENT KILNS	0.9	CAPTURE CO2	L	U
		USE ALTERNATE BUILDING MATLS.	L	P
PULP&PAPER LIME KILNS	1.9	CAPTURE CO2	M/H	U
		INCREASE PULP YIELDS OF KRAFT MILLS	L/M	P
		ALTERNATE PULPING PROSSES, TMP, CTMP	L/M	P
		USE RECYCLED PAPER	L/M	P
METHANOL/AMMONIA	0.1	CAPTURE CO2	L	U
		ALTERNATE PROSSES TECHNOLOGY	L	P
MISC. CHEM. IND.	.0	CAPTURE CO2	L	U
		ALTERNATE PROSSES TECHNOLOGY	L	P/E
ALUMINUM SMELTING	0.80	CAPTURE CO2	L	U
		ALTERNATE PROSSES TECHNOLOGY	L	E/U
CO BOILERS	0.00	CAPTURE CO2	L	U
GAS PLANT/FIELD USE	.0	CAPTURE CO2	L	U
		REDUCE DOMESTIC CONSUMPTION OF NATURAL GAS	L	P
		REDUCE EXPORTS OF NATURAL GAS	L	P

TABLE VI-1 CARBON DIOXIDE REDUCTION OPPORTUNITIES

SECTOR/SUB-SECTOR	1988 EMISSION (%)	CO2 REDUCTION METHOD	CO2 REDUCTION POTENTIAL	STATE OF DEVELOPMENT
STATIONARY COMBUSTION				
GAS UTILITIES	2.9	SWITCH TO ELECTRICITY DRIVEN COMPRESSORS	L	P
		IMPROVE EQUIPMENT EFFICIENCY	L	P
		ENERGY MANAGEMENT/CONSERVATION	L	P
		REDUCE EXPORTS OF NATURAL GAS	L	P
		DOWNSTREAM CONSERVATION	L/M	P
POWER GENERATION	1.3	COGENERATION	L/M	P
		ALTERNATE ENERGY (SOLAR, WIND, TIDAL, ETC)	L	P
		IMPROVE GENERATING EFFICIENCY	L	P
		ALTERNATE FUEL FOR THERMAL GENERATION	L	P
		NUCLEAR POWER	L	P
		DOWNSTREAM ENERGY CONSERVATION	L	P
		CAPTURE CO2- THERMAL STATIONS	L	U
		EXPAND HYDRO POW . NETWORK	L/M	P
RESIDENTIAL/AGRICULTURAL	5.5	ENERGY CONSERVATION	L/M	P
		SWITCH TO ELECTRIC HEATING	L	P
		HEAT PUMPS	L	P/E
		ALTERNATE ENERGY (SOLAR, WIND, TIDAL, ETC)	L	P/E
		ARCHITECTURAL DESIGN FOR OPTIMUM ENERGY USE	L	P
		PROPER FURNACE/HEATER TUNING & MAINTENANCE	L	P
		IMPROVE INSULATION	L	P
		INCREASE HEATING EFFICIENCY	L	P
		SWITCH TO GAS (FROM OIL ETC)	L/M	P
		EFFICIENT NEW HOUSING	L/M	P
		WASTE HEAT USE/ DISTRICT HEATING	L	P
COMMERCIAL/PUBLIC ADMIN.	3.3	IMPROVE AIR CONDITIONING EFFICIENCY	L	P
		ALTERNATE AIR CONDITIONING TECHNOLOGY	L	P
		ENERGY MANAGEMENT/CONSERVATION	L	P
		IMPROVE INSULATION	L	P
		ALTERNATE BUILDING MATERIALS	L	P/E
		SWITCH TO GAS (FROM OIL ETC)	L	P
		IMPROVE HEATING EFFICIENCY	L	P
		HEAT PUMPS	L	P
		DISTRICT HEATING	L	P
		ALTERNATE ENERGY (SOLAR, WIND, TIDAL, ETC)	L	P
FUEL WOOD	0.8	REDUCE USE	L	P
		IMPROVE COMBUSTION EFFICIENCY	L	P

TABLE VI-1 CARBON DIOXIDE REDUCTION OPPORTUNITIES

SECTOR/SUB-SECTOR	1988 EMISSION (%)	CO2 REDUCTION METHOD	CO2 REDUCTION POTENTIAL	STATE OF DEVELOPMENT
INDUSTRIAL		ENERGY MANAGEMENT	M/H	P
		ENERGY CONSERVATION/REUSE	M/H	P
		CAPTURE CO2	M/H	U
		ALTERNATE FUELS (HIGHER H/C RATIOS)	L/M	P
		RENEWABLE ENERGY (SOLAR, WIND, TIDAL, ETC.)	L/M	P/E
		IMPROVE USE OF RAW MATERIALS	L/M	P
		IMPROVE BOILER EFFICIENCY	L/M	P
		COGENERATION	M/H	P
PULP&PAPER	24.6	IMPROVE PULPING YIELDS	H	P
		ALTERNATE PULPING TECHNOLOGY	H	P
		INTEGRATED PULP&PAPER MILLS	M/H	P
WOOD PROD.	3.9	IMPROVE DRY KILN ENERGY EFF.	M	P
		ALTERNATE DRY KILN TECHNOLOGY	L	P
		HIGHER WOOD PRODUCT YIELDS	L	P
		COGENERATION AT SAWMILLS	L	P
PRIMARY METALS	0.1			
CHEM. IND.	0.3			
NON-MET. MINERALS	0.3	USE DRY PROCESS INSTEAD OF WET PROCESS FOR CEMENT PRODUCTION	L	P
PETROLEUM REF.	1.6			
OTHER MFG.	1.3			
MINING	1.7			
OTHER IND.	1.2			

TABLE VI-1 CARBON DIOXIDE REDUCTION OPPORTUNITIES

SECTOR/SUB-SECTOR	1988 EMISSION (%)	CO2 REDUCTION METHOD	CO2 REDUCTION POTENTIAL	STATE OF DEVELOPMENT
MOBILE COMBUSTION SOURCES				
ROAD	13.3	FUEL EFFICIENT VEHICLES-IMPROVE ENGINES, REDUCE WEIGHT, DRAG, ROLLING FRICTION	M/H	P/E
		SWITCH TO CNG, LNG	M/H	P
		HYDROGEN FUELS	H	E/U
		ELECTRIC CARS, BUSES	M/H	P/E
		IMPROVE VEHICLE MAINTENANCE & TUNING -MANDATORY TESTING	L	P.
		ALTERNATE DRIVING HABITS	L	P
		STAGGERED WORKING HOURS	L	P
		IMPROVE PUBLIC ROADS	L	P
		URBAN PLANNING- LESS COMUTING	M	P
		CAR POOLING	L/M	P
		URBAN TAFFIC COORDINATION	L	P
		HIGHER CAPACITY TRUCKING	L	E
		BICYCLE LANES ON PUBLIC ROADS	L/M	P
RAIL	1.9	ELECTRIFIED TRAINS	L	P
		IMPROVE FUEL EFFICIENCY	L	P
		REDUCE TRACK GRADES(TUNNELING)	L	P
		PROPER MAINTENANCE/TUNING	L	P
MARINE	2.5	SWITCH FUELS	L	P
		IMPROVE HULL & PROPELLOR DESIGNS	L	P
		SAILS ON CARGO VESSELS	L	P
		SOLAR POWER	L	P
		REDUCE HARBOUR BACKLOG	L	P
		SHORE ELECTRICITY WHILE IN DOCK	L	P
		PROPER MAINTENANCE/TUNING	L	P
		IMPROVE ENERGY EFFICIENCY	L	P
AIR	2.6	FUEL EFFICIENCY IMPROVEMENTS	L	P
		REDUCE AIRPORT CONGESTION	L	P
		PROPER MAINTENANCE/TUNING	L	P
OFF-ROAD	0.4	ALTERNATE FUELS-CNG, PROPANE	L	P
		PROPER MAINTENANCE/TUNING	L	P
		IMPROVE FUEL EFFICIENCY	L	P
		SWITCH TO ELECTRIC EQUIPMENT	L	P
		REDUCE USE	L	P

TABLE VI-1 CARBON DIOXIDE REDUCTION OPPORTUNITIES

SECTOR/SUB-SECTOR	1988 EMISSION (%)	CO2 REDUCTION METHOD	CO2 REDUCTION POTENTIAL	STATE OF DEVELOPMENT
SOLID WASTE DISPOSAL				
MUNICIPAL	0.3	COGENERATION	L	P
LANDFILL GAS	0.4	LANDFILL GAS USE TO DISPLACE OTHER FUELS	L	P
INDUSTRIAL	.0			
WOOD WASTE	10.5	USE WOOD WASTE FOR OTHER PRODUCTS	M/H	P
		YARD WASTE UTILIZATION	M	P
		IMPROVE PRODUCT YIELD-LESS WASTE	M/H	P
		COGENERATION AT SAWMILLS	M	P
TOTAL SOLID WASTE DISPOSAL	11.1			
OPEN BURNING		REDUCE LOGGING BY BETTER UTILIZATION OF WOOD WASTE THROUGH:		
PRESCRIBED BURNING	15.8	WHOLE TREE CHIPPING	H	P
WILD FIRE	0.4	RECYCLING PAPER PRODUCTS	H	P

P - Proven
E - Emerging
U - Unproven
L - Low
M - Moderate
H - High

On a global scale, the prospect of decreasing atmospheric CO_2 through intensive forest management and afforestation is not encouraging. For example, a recent investigation by the United States Department of Energy concluded that to capture enough carbon to equal the 1980 emission of CO_2 from burning of fossil fuels would require: (i) a doubling of the net annual productivity of the world's closed forests (or trees planted over an area equal to the total area deforested in the world to date); (ii) cessation of all deforestation; and (iii) prevention of burning or decay of all forest products (Alaback, 1989). It is apparent that the amount of carbon that can be captured by forests is so small, relative to the total amount of CO_2 in the atmosphere, that potential reduction programs need to focus more on emissions than on sinks. If vegetation management were to be carried out as part of a CO_2 reduction program there would be the greatest impact if it involved revegetation or afforestation of areas presently barren or sparsely vegetated.

Most of the CO_2 reduction measures listed in Table VI-1 were rated as having a low potential impact on emissions. This sometimes happens because the individual sector or subsector contribution to total CO_2 emissions is small. Most of these measures offer incremental reductions in CO_2 emissions. Energy management and conservation, improved efficiency, proper maintenance and tuning, switching to higher hydrogen to carbon fuels, etc. are obvious examples. It is important to remember, however, that collectively these incremental measures will have a significant affect on total CO_2 emissions.

Some of the CO_2 reduction measures were rated as having a range of potentials, such as low/moderate or moderate/high. In these cases, the extent that the individual measure could be applied resulted in the varying impacts.

The opportunities which were perceived as having the highest potential for CO_2 reductions or deserved special attention, are discussed further in the next section.

B. Promising Opportunities for Reducing CO_2 Emissions

1. Technological Choices

The more promising opportunities for reducing CO_2 emissions and those deserving special attention are listed in Table VI-2 by source sector. Most of the opportunities involve, or ultimately lead to, reduced energy consumption. The common consequences of reduced energy consumption include reduced CO_2 and other air emissions, reduced costs to the consumer, extended life of energy reserves, but potentially higher unit energy costs charged by utilities and suppliers may result. Costs were usually avoided as disadvantages. Most opportunities will involve some capital investment which may be paid out in a given period through reduced energy costs. It is beyond the scope of this report to deal with the economics which vary from company to company.

TABLE VI-2 ADVANTAGES AND DISADVANTAGES OF SELECTED CO2 REDUCTION OPPORTUNITIES

GROUPING SECTOR SUB-SECTOR	CO2 REDUCTION METHOD	ADVANTAGES	DISADVANTAGES	COSTS	BENEFITS
PROCESS SOURCES					
PULP&PAPER LIME KILNS	ALTERNATE PULPING PROSSES	ELIMINATE LIME KILNS	LIMITED BY MARKET FOR GRADES OF PULP EFFLUENT TREATMENT PROBLEMS	H	H
	USE RECYCLED PAPER	REDUCED LIME REQUIREMENTS	NEW PROCESS EQUIPMENT REQUIRED INK AND FILLER ETC DISPOSAL PROBLEMS	M	M/H
GAS PLANT/FIELD USE	REDUCE USER CONSUMPTION OF GAS	EXTENDED RESOURCE LIFE REDUCE OTHER POLLUTANT EMISSIONS	MANY USERS AND TECHNOLOGIES INVOLVED MAY INCREASE UNIT FUEL COSTS	L/M	L
STATIONARY COMBUSTION					
POWER GENERATION	COGENERATION	MORE EFFICIENT USE OF ENERGY REDUCE OTHER POLLUTANT EMISSIONS	SUITED TO LARGE APPLICATIONS ONLY	M/H	M
	DOWNSTREAM ENERGY CONSERVATION	DEFER FUTURE GENERATION PROJECTS REDUCE OTHER POLLUTANT EMISSIONS	MANY USERS AND TECHNOLOGIES INVOLVED MAY INCREASE UNIT FUEL COSTS	L/M	L/M
RESIDENTIAL/ AGRICULTURAL	ENERGY CONSERVATION	EXTENDED RESOURCE LIFE REDUCE OTHER POLLUTANT EMISSIONS	DIFFICULT TO IMPLEMENT CONSISTENTLY MAY INCREASE UNIT FUEL COSTS	L/M	M
	ARCHITECTURAL DESIGN FOR OPTIMUM ENERGY USEAGE	EXTENDED RESOURCE LIFE REDUCE OTHER POLLUTANT EMISSIONS	DIFFICULT TO RETROFIT LONG LAG TIME BEFORE IMPACT FELT	M/H	L
	PROPER FURNACE/HEATER TUNING	EXTENDED RESOURCE LIFE REDUCE OTHER POLLUTANT EMISSIONS	DIFFICULT TO IMPLEMENT DIFFICULT TO MONITOR	L	L
	IMPROVE INSULATION	EXTENDED RESOURCE LIFE REDUCE OTHER POLLUTANT EMISSIONS	LONG LAG TIME BEFORE IMPACT FELT DIFFICULT TO RETROFIT	L/M	L
	EFFICIENT NEW HOUSING	EXTENDED RESOURCE LIFE REDUCE OTHER POLLUTANT EMISSIONS	NEED IMPROVED VENTILATING SYSTEMS LONG LAG TIME BEFORE IMPACT FELT	L/M	L/M
COMMERCIAL/ PUBLIC ADMINISTRATION	ENERGY MANAGEMENT/CONSERVATION	EXTENDED RESOURCE LIFE REDUCE OTHER POLLUTANT EMISSIONS	DIFFICULT TO IMPLEMENT CONSISTENTLY MAY INCREASE UNIT FUEL COSTS	L/M	M
	HEAT PUMPS	MORE EFFICIENT ENERGY USE REDUCE OTHER POLLUTANT EMISSIONS	LIMITS TO APPLICATION	M	L
	EDUCATION, PUBLIC INFORMATION PROGRAMS, GOVERNMENT LEADERSHIP	BROAD REACHING EFFECTS	VERY SLOW PROCESS	L/M	L/M
INDUSTRIAL	ENERGY MANAGEMENT/CONSERVATION	EXTENDED RESOURCE LIFE REDUCE OTHER POLLUTANT EMISSIONS	PRACTICLE LIMITATIONS INCREASE CAPITAL COSTS	M	M
	INCREASE BOILER EFFICIENCY	EXTENDED RESOURCE LIFE REDUCE OTHER POLLUTANT EMISSIONS	PRACTICLE LIMITATIONS INCREASE CAPITAL COSTS	M	M
PULP&PAPER	IMPROVE PULPING YIELDS	INCREASE PRODUCTION REDUCE OTHER CONTAMINANTS	PRACTICLE LIMITATIONS	M	M
	ALTERNATE PULPING TECHNOLOGY	INCREASE PRODUCTION REDUCE CONSUMPTION OF TREES	LIMITED BY MARKET FOR GRADES OF PULP EFFLUENT TREATMENT PROBLEMS	M	M

TABLE VI-2 ADVANTAGES AND DISADVANTAGES OF SELECTED CO2 REDUCTION OPPORTUNITIES

GROUPING SECTOR SUB-SECTOR	CO2 REDUCTION METHOD	ADVANTAGES	DISADVANTAGES	COSTS	BENEFITS
MOBILE COMBUSTION					
ROAD VEHICLES	FUEL EFFICIENT VEHICLES -ENGINE,DRAG,ROLLING,WEIGHT	EXTENDED RESOURCE LIFE REDUCE OTHER POLLUTANT EMISSIONS	MAY INCREASE OTHER CONTAMINANTS LONG LAG TIME BEFORE IMPACT FELT	H	M/H
	SWITCH TO CNG, LNG	REDUCE OTHER POLLUTANT EMISSIONS	USER ACCEPTANCE AVAILABILITY OF SUPPLY	H	M
	ELECTRIC CARS, BUSES	REDUCE OTHER POLLUTANT EMISSIONS NOISE REDUCTION	INFASTRUCTURE REQUIREMENTS LIMITED RANGE/PERFORMANCE	H	M/H
	IMPROVE PUBLIC ROADS	REDUCE GRID LOCK REDUCE SOCIAL TENSION	INCREASE IN DRIVING REDUCE LAND USE	H	M
MARINE	SHORE ELECTRICITY IN DOCK	REDUCE OTHER POLLUTANT EMISSIONS	SHIPS MAY NOT BE SUITED TO THIS INFASTRUCTURE REQUIREMENTS	M/H	L
AIRCRAFT	FUEL EFFICIENCY IMPROVEMENTS	REDUCE ENERGY CONSUMPTION MAY REDUCE OTHER CONTAMINANTS	DIFFICULT TO ENFORCE LONG LAG TIME BEFORE IMPACT FELT	H	L
	REDUCE AIRPORT CONGESTION	REDUCE ENERGY CONSUMPTION	COSTS/SPACE REQUIREMENTS IMPACT ON NEIGHBOURS	H	L/M
SOLID WASTE DISPOSAL					
WOOD WASTE	USE WOOD WASTE FOR OTHER PROD.	INCREASE VALUE ADDED PRODUCTS REDUCE CONSUMPTION OF TREES	VOC EMISSIONS FROM GLUES USED	L/M	H
	YARD WASTE UTILIZATION	INCREASE PRODUCTIVITY REDUCE CONSUMPTION OF TREES	IMPURITY PROBLEMS EQUIPMENT REQUIREMENTS	L/M	H
	COGENERATION	EFFICIENT USE OF ENERGY/WASTE INCOME FROM WASTE DISPOSAL	LIMITED APPLICATIONS	M/H	M
SLASH BURNING					
SLASH BURNING	WHOLE TREE CHIPPING (BETTER USE OF RESOURCES)	REDUCE TREE CONSUMPTION REDUCE ENERGY CONSUMPTION	CAPITAL COSTS PROCESS CHANGES	M	M/H
	RECYCLE PAPER PRODUCTS (REDUCE LOGGING)	REDUCE TREE CONSUMPTION REDUCE ENERGY CONSUMPTION	CAPITAL COSTS PROCESS CHANGES	L/M	M/H

L - Low
M - Moderate
H - High

Energy management and conservation can be applied to nearly every sector or subsector within mobile and stationary combustion. Much can be achieved simply by changing energy use practices. For example, lights can be manually turned off in office and commercial buildings during off hours. Computerized sensors can also perform similar functions. Lights can be programmed to come on only when someone is present. Thermostats can automatically turn down overnight and then turn up during the day. Similarly in industry, sensors and controllers can improve fuel efficiency in boilers and other processing equipment. Convenience and potentially improved product quality or yield, as well as reduced fuel costs can often offset the capital investment needed.

Alternative modes of transportation, industrial processes or construction practices can result in major fuel consumption reductions. New vehicles and facilities can make good use of energy efficient technology. Existing vehicles and facilities, however, can be costly to retrofit and may require complete reconstruction. In most cases, this simply will not happen. Replacement of existing vehicle fleets, buildings and industries takes about 20 years for vehicles and 50 to 100 years for buildings and industries.

While the major incentive for alternative modes of transportation and construction practices is a cost saving, industries also can increase productivity. For example, the Kraft process typically achieves a pulp yield of 45% to 50% on a weight basis. Improvements in processing can increase the yield to 60%. Alternatively, CTMP mills typically achieve 90% pulp yields and can get up to 95%.

The use of recycled materials (paper, metals and glass) as well as increased use of tree roots, limbs and bark, impact on CO_2 emissions in several ways. Recycled materials usually require less energy to remanufacture than if the equivalent amount of product was produced from raw materials. This is especially true for aluminum. Using recycled materials reduces the demand for raw materials and reduces the amount of energy consumed in obtaining, transporting and refining or processing the raw materials. Using recycled paper and making better use of trees leaves more trees standing. If these trees are not cut down, they will not contribute to CO_2 emissions from pulp mills, sawmills, beehive burners, slash burning, etc.

The extraction of raw materials also negatively impacts the environment. Reducing the demand for raw materials by using recycled material also reduces these impacts. The life span of the non-renewable resources is also prolonged for future generations to enjoy.

Switching to alternative fuels such as CNG and LNG reduce CO_2 emissions as well as other air emissions. Depending on the fuel, CO_2

emissions can be reduced by 25% to 50% of the original level by switching to CNG or LNG.

Switching to hydrogen or electricity can eliminate CO_2 emissions depending on the means used to produce the hydrogen or electricity. The negative impacts on the environment associated with hydro and nuclear power are well known. It is not a simple nor a foregone conclusion that reducing or eliminating CO_2 emissions by switching to hydro or nuclear power is better than emitting the CO_2.

Improved transportation networks, such as improved roadways and larger airports, which reduce congestion, thereby reducing the amount of energy consumed, may encourage a certain amount of additional travel because of increased convenience. On the other hand, reducing congestion by improving alternative modes of transportation, such as buses, commuter trains and sea buses, bicycle lanes, reduce fuel consumption and congestion. Staggered working hours have a similar effect.

Using wood and municipal waste to generate energy, thus displacing other fuels, will result in a net reduction of CO_2 emissions and extend the reserve life of our natural resources.

2. Policy and Programs for Reducing CO_2 Emissions

The intention of this Section is not to recommend policies which could be pursued by the Ministry. Instead, it is desirable to discuss several CO_2 reduction opportunities which are broad in nature and which affect more than one sector.

In order to meet an ambitious goal of reducing CO_2 emissions to 80% of the 1988 level, as suggested in the Toronto Conference on Climate, it is essential to first understand the nature of the greenhouse effect and the host of cause-effect relationships involved. Consequently, educating the public is a first step. Society must be aware that its life style has an impact on the amount of CO_2 emitted and the CO_2 reductions possible. Society must choose to be less wasteful, to reduce its consumption of energy and materials and to switch to using forms of energy which emit less CO_2 (or no CO_2). Society must choose to do so even though using alternative forms of energy may be more costly initially. It must do so even though reducing, reusing and recycling takes more effort or is less convenient. Society must change its lifestyle because the alternative is even more costly and more inconvenient.

Education and awareness take time before a noticeable impact is felt. Other measures are needed in the short term. These measures include higher prices or increased taxes on non-essential energy and material consumption and non-reusable containers or excess packaging.

The forestry industry, because of its massive presence in British Columbia, may be required to take a leading role in the effort to reduce CO_2 emissions. As the 1988 inventory indicates, nearly two-thirds of the CO_2 emissions are directly attributable to the forestry industry. In addition to the energy management/conservation programs, switching to alternative fuels, increasing energy efficiency in their combustion devices and cogeneration, the forestry sector can reduce CO_2 emissions through good resource management. High yield logging, where the whole tree is used as a fibre source, would reduce the amount of trees cut to produce the same amount of product. Increased sawmill and pulp mill yields should benefit the forest industry as well as reduce CO_2 emissions. Switching to high yield pulping processes, increasing the utilization of wood wastes for the manufacture of final products and building integrated pulp and paper mills could be expected to substantially lower CO_2 emissions.

Utilities can also assist in achieving substantial reductions in CO_2 emissions. This could be achieved through the design of rate schedules for electricity and natural gas that encourage more efficient energy use.

Because mobile sources are a major source of CO_2 emissions, significant reductions could probably be achieved by improvements in the efficiency of moving people and goods and through land use planning to reduce the need for motorized transportation. Obvious possibilities are placement of people near their work, public transit, ride sharing and other similar improvements.

VII. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

1. The CO_2 emissions estimates for 1988 and 2005 for the five categories studied are as follows (rounded to the nearest 100 kt CO_2):

	CO_2 Emissions (kt CO_2)	
	1988	2005
Process	3,200	3,800
Stationary Combustion	41,000	55,500
Mobile Combustion	17,400	22,800
Solid Waste Disposal	9,400	7,300
Prescribed Burning	13,300	9,300
Total*	84,400	98,700

2. The CO_2 emissions arising from fuel combustion for 1988 and 2005 are as follows (rounded to the nearest 100 kt CO_2):

	CO_2 Emissions (kt CO_2)	
Process	1988	2005
Natural Gas and LPGs	12,700	17,400
Refined Petroleum Products	23,800	28,600
Coal and Coke	900	2,100
Wood Waste and Fuel Wood	15,300	15,300
Pulping Liquors	14,700	15,000
Solid Waste	600	700
Renewable	0	600
Total*	67,800	82,300

* may not add to total due to rounding

3. The top five CO_2 source sectors and subsectors for 1988 and 2005 by rank in 1988 (rounded to the nearest 100 kt CO_2):

	CO_2 Emissions (kt CO_2)	
Process	1988	2005
Pulp and Paper	20,800	22,600
Slash Burning	13,300	9,300
Road Vehicles	11,200	15,500
Wood Waste Incineration	8,800	6,600
Residential/Agricultural	4,600	7,100
Total*	58,700	61,100
% of Total Anthropogenic CO_2 Emissions	70%	62%

* may not add to total because of rounding

4. The CO_2 sink estimates for 1988 are as follows (rounded to the nearest 100 kt):

	CO_2 Sinks (kt C)	Average Values (kt CO_2)
Forests	54,000	198,000
Rivers	900	3,500
Lakes	300	1,200
Wetlands	200	600
Total*	55,400	203,200

* may not add to total because of rounding

CO_2 sink estimates for 2005 could not be quantified but would intuitively be approximately equal to the 1988 estimates.

5. The inventory of CO_2 emissions prepared in this study is 38% higher than the estimate made for B.C. by Environment Canada for 1987 of 61,100 kt CO_2. This results from use of better data and inclusion of additional sources.

6. Lack of data precludes more complete estimation of CO_2 sinks. The estimate from this study is expected to be lower than actual because data are not available to quantify adequately CO_2 fixation by all wetlands and rivers.

7. There is good agreement between the EMR and EMPR energy consumption estimates for 1988 and 2005 for the fuel combustion categories. Using these data, overall growth rates in CO_2 emissions from fuel combustion were 26% for both forecasts.

8. A more complete inventory of natural CO_2 emissions and sinks is needed before a proper CO_2 balance can be produced for B.C. The emission sources to include are human and animal respiration and biomass decomposition. The sinks which could be added are a portion of the ocean and any bodies of water not included in this study.

9. The forecast of fuel consumption used in this inventory, which was prepared by the EMPR (1986), is soon to be superceded. Recent trends in immigration were not incorporated in the 1986 forecast. Future energy consumption is likely to be higher for many sectors than given in the available forecast.

10. The inventories and hence the forecasts of CO_2 emissions from the marine and aviation sectors are based on fuel purchased in B.C., which is a first approximation to fuel actually consumed in B.C.

11. Public education programs to raise the level of awareness of the impacts of our lifestyle on CO_2 emissions, policies consistent with energy and natural resource conservation and governments setting an example are necessary aspects of any CO_2 reduction program.

12. The forestry sector accounts for over two-thirds of the anthropogenic CO_2 emissions in 1988. This trend will continue into 2005. The industry should take steps, not only to reduce CO_2 emissions, but to set an example for other industries.

13. CO_2 is not solely responsible for the greenhouse effect. Opportunities to reduce other greenhouse gases must aslo be considered.

B. Recommendations

1. Update the CO_2 emissions inventory using energy consumption projections for 2005 in the soon to be released B.C. Energy, Mines and Petroleum Resources, Energy Supply and Requirements Forecast - 1990-2005.

2. Verify wood waste incineration estimates for 1988 (and 2005 if available). One study for the Ministry of Forests is in progress, which will update the wood waste inventory and deposition to 1989.

3. Resolve the differences between fuel consumption and fuel purchased in B.C. for the marine and aviation sectors.

4. To more accurately assess the carbon cycling role of forests it is necessary to obtain data on carbon fixation rates as well as decomposition rates across a range of biogeoclimatic zones and ecosystems for at least three stages of forest stand development: (i) the early phase after harvesting when there is expected to be a net release of carbon; (ii) the rapid growth phase when there is a net gain of carbon in the forest sink; and (iii) old-growth forests in which fixation of carbon is approximately equal to that released by decomposition.

5. In conjunction with the other provinces, resolve the difficulties which arise in calculating emissions from the mobile combustion category because of differences in fuel purchased in the province and fuel consumed in the province.

6. Develop sufficient resolution in the data base to provide disaggregation of transportation source emissions by regional district.

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APPENDIX I

CO_2 EMISSION FACTORS

The following Table (S-3) was taken from:

> Jaques, A.P., "National Inventory of Sources and Emissions of CO_2 (1987)", Management and Emergencies Branch, Conservation and Protection, Environment Canada, June 1989.

Conversion factors used in this study were taken from this table, or this reference, unless otherwise noted.

Table S.3 CO_2 EMISSION FACTORS

SOURCE	Carbon	EMISSION FACTORS Carbon (t/TJ)	Carbon Dioxide (t/TJ)
GASEOUS FUELS	(g/m^3)		
Natural gas	512.46	13.55	49.68
LIQUID FUELS	(g/l)		
Motor gasoline	642.60	18.54	67.98
Kerosene	695.20	18.45	67.65
Aviation gasoline	634.20	18.92	69.37
Propane	416.65	16.32	59.84
Diesel Oil	745.75	19.28	70.69
Light Oil	771.28	19.94	73.11
Heavy Oil	814.15	19.51	71.54
Aviation Turbo	694.17	19.32	70.84
SOLID FUELS	(g/kg)		
U.S. Bituminous	702.97	23.44	85.95
Cdn. Bituminous	692.95	23.65	86.72
Sub-Bituminous	507.63	25.69	94.20
Lignite	425.66	27.73	101.68
Anthracite	702.97	23.44	85.95
Petroleum Coke	898.92	25.75	94.42
Fuel Wood	400.00	22.22	81.47
Slash Burning	400.00	22.22	81.47
Incineration	250.00	-	-
INDUSTRIAL SOURCES	(g/kg)		
Cement Production	140.00[a]	-	-
Ammonia Production	430.00[b]	-	-
Pulp & Paper Production	410.00[c]	29.29	107.38

a - of cement produced
b - of ammonia produced
c - of spent pulping liquors consumed

The following table was taken from Appendix 2.G in:

> Council of Provincial Energy Ministers, "Report of the Federal/Provincial/Territorial Task Force on Energy and the Environment", August 1989.

Conversion factors for LPG's and renewables were taken from this table.

TABLE 1

CONVERSION FACTORS FOR FOSSIL FUELS & RENEWABLE ENERGY IN CANADA:
SECONDARY DEMAND

(Carbon Dioxide - Tonnes Per Terajoule)

Fuel Type	Residential	Commercial	Industrial	Transportation
Natural Gas	(49.46)	(49.46)	(49.46)	(49.46)
RPPs	--	--	--	--
Naphtha	--	--	--	--
Motor Gasoline	(67.98)	--	--	(67.98)
Aviation Gasoline	--	(69.37)	--	(69.37)
Aviation Turbo	--	(70.84)	--	(70.84)
Kerosene	(67.65)	(67.65)	(67.65)	--
Light Fuel Oil	(73.11)	(73.11)	(73.11)	--
Diesel Fuel Oil	(70.69)	(70.69)	(70.69)	(70.69)
Heavy Fuel Oil	(80.65)	(80.65)	(80.65)	(80.65)
Petroleum Coke	--	--	(100.00)	--
LPGs	(70.22)	(70.22)	(70.22)	(59.80)
Coal	(Table 3)	(Table 3)	(Table 3)	--
Coke & Coke Oven Gas	--	--	(Table 4)	--
Renewables				
Wood	(81.47)	--	(Table 5)	--

-- Indicates that the fuel or product is not used or information is not required at this level.

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MISCELLANEOUS CONVERSION FACTORS

Incineration	0.9 tonnes CO_2/tonne waste. This was calculated from the emission factor for carbon (Jaques, 1989, p. 28).
C & C	90 tonnes CO_2/tJ C & C. This was estimated as the average of the values for the coal and the coke.
Still Gas	59.84 tonnes CO_2/tJ. The value for propane was assumed.
Landfill	0.17 tonnes CO_2/tonne solid waste. This is an estimate by BHLA personnel.
Prescribed Burning	1534 g/kg wood burned. From Hawkes, 1989 and is average of smoldering and flaming combustion.
Fuel Consumption	Silvicultural slash burning: 8 kg/m^2 land area Wildlife habitat improvement: 2 kg/m^2 land area (from Hawkes, 1989)

APPENDIX II-A

VEHICLE TYPE DEFINITIONS

The following definitions of vehicle types were taken from:

Environmental Applications Group Ltd. et al, "1985 Lower Mainland Emission Inventory, D: Mobile Sources, Volume 2: Methodology", prepared for GVRD Pollution Control, May 1988.

LDGV	-	light duty gasoline vehicles; any gasoline fueled motor vehicle designated primarily for transportation of persons and having a seating capacity of 12 persons or fewer.
LDGT1	-	light duty gasoline powered trucks 1; any gasoline fueled motor vehicle designated primarily for transportation of property and rated at 2722 kg (6000 lb) GVW or less.
LDGT2	-	light duty gasoline powered truck 2; any gasoline fueled motor vehicle designated primarily for transportation of property and rated between 2722 kg (6001 lb) and 3856 kg (8500 lb) GVW inclusive.
HDGV	-	heavy duty gasoline powered vehicles, any gasoline fueled motor vehicle designated primarily for the transportation of property and rated at more than 3856 kg (8500 lb) GVW, or designated primarily for transportation of persons and having a capacity of more than 12 persons.
LDDV	-	light duty diesel powered vehicles; any diesel fueled motor vehicle designated primarily for transportation of persons and having a capacity of 12 persons or fewer.
LDDT	-	light duty diesel powered trucks; any diesel fueled motor vehicle designed primarily for transportation of property and rated at 3856 kg (8500 lb) or less.
HDDV	-	heavy duty diesel powered vehicles, any diesel fueled motor vehicle designated primarily for transportation of property and rated at more than 3856 kg (8500 lb) GVW, or designated for transportation of persons and having a capacity of more than 12 persons.
MC	-	motorcycles; any motor vehicle designed to travel with not more than three wheels in contact with the ground, and weighing less than 680 kg (1500 lb).

APPENDIX II-B

CALCULATION OF APPORTIONING FUEL CONSUMPTION TO VEHICLE TYPES

GASOLINE VEHICLES

Type of Vehicle	Efficiency (L/100 km)	V km T / V yr	Vehicle Distribution	# of Vehicles	V km T (1000s)	Gasoline (kL)	Gasoline Distribution
LDGV	13.3	14,000	71.38	1,375,647	19,259,058	2,561,455	62.99
LDGT1	18.0	15,300	6.65	128,164	1,960,909	352,964	8.68
LDGT2	18.0	15,800	16.15	311,148	4,916,138	884,905	21.76
HDGF	25.5	19,000	2.72	52,486	997,234	254,295	6.25
MC	7.1	3,100	3.10	59,693	185,048	13,138	0.32
				1,927,138	27,318,388	4,866,756	100

DIESEL VEHICLES

Type of Vehicle	Efficiency (L/100 km)	V km T / V yr	Vehicle Distribution	# of Vehicles	V km T (1000s)	Gasoline (kL)	Gasoline Distribution
LDDV	10.0	14,000	26.16	16,813	343,386	34,339	2.64
LDDT	11.3	15,500	19.91	12,795	290,145	32,786	2.52
HDDV	49.4	49,300	53.93	34,662	2,500,102	1,235,050	94.84
				64,270	3,133,633	1,302,125	100

APPENDIX II-C

CALCULATION OF CO_2 EMISSIONS FROM PRESCRIBED BURNING

Land areas burnt in 1988 (Fuglen, 1990 and Spittlehouse, 1990):

Silvicultural burning	88,756 ha
Fire hazard slash burning	1,484 ha
	90,240 ha
Fish and wildlife habitat	64,888 ha
Range grass	7,938 ha
	72,826 ha

CO_2 Emissions:

Emission factor		1534 g/kg wood
Fuel consumption	silviculture areas	8 kg/m^2
	wildlife areas	2 kg/m^2

(a) Silvicultural Areas

$$CO_2 = 90{,}240 \times 8 \times 1{,}534 \times \frac{10{,}000}{10^6} = 11{,}100 \text{ kt}$$

(b) Wildlife Areas

$$CO_2 = 72{,}826 \times 2 \times 1{,}534 \times \frac{10{,}000}{10^6} = 2{,}200 \text{ kt}$$

(c) Total

CO_2 = 13,300 kt

APPENDIX III

METHODOLOGY FOR CALCULATING CO_2 UPTAKE BY FORESTS

APPENDIX III

ANNUAL GROWTH RATES AND BIOMASS OF BOLEWOOD PLUS BARK FOR COASTAL AND INTERIOR FOREST TYPES (SOURCE: SMITH 1976)

Forest types	Annual Growth Rate (m^3 ha^{-1}) Immature	Mature	Biomass of bolewood plus bark per volume of wood (kg m^3)
Coast			
Spruce	7.9	0.8	380
Hemlock	5.0	1.9	487
Cedar	3.6	2.0	364
Douglas fir	4.5	1.8	585
Interior			
Douglas fir	1.8	0.6	605
Cedar	2.4	1.7	370
Hemlock	2.9	1.3	514
Fir	2.0	0.6	412
Spruce	2.6	0.8	437
White pine	3.1	0	423
Lodgepole pine A	2.5	1.1	447
B	1.8	0.7	447
Yellow pine	0.6	0.4	529
Larch	2.2	1.3	660
Black cottonwood	2.2	2.2	392
Birch	1.0	-	591
Aspen	1.8	1.0	441

APPENDIX III

STEPS USED FOR ESTIMATION OF CO_2 SINKS IN BRITISH COLUMBIA FORESTS

Step 1: For each inventory biozone, Bickerstaff et al (1981) indicated the proportions of major tree species on a volume basis but not on a land area basis. To estimate the latter, it was necessary to recognize that species height differences can influence the land area needed to achieve a given volume of standing crop. Therefore, height data from Hegyi et al (1979) were used to weigh the proportion of species by volume when these were converted to proportions of area occupied by the different species groups. From the site index curves in Hegyi et al (1979) three heights on medium sites were assumed to represent the average height of a given stand. The heights of immature forest were taken to be the mid-point of the rising half of the age-height curves. From this standard position on each curve, species differences in height were used as weighing factors of the species proportions by volume to convert the latter to an area basis.

Step 2: The areas of all species groups for three maturity classes on productive forest land were calculated. For the present analysis the absolute area of productive forest land given by Bickerstaff et al. (1981) was used.

Step 3: On the assumption that the growth of forest trees in recent years has remained relatively the same, the next step was to compute the annual growth of forests in British Columbia using the growth rates listed in Smith (1976) and reproduced in Appendix IV-1. Annual growth estimates for both immature and mature/overmature forests were calculated. The coastal forests were considered to include inventory biozones A to C, and the interior forests, biozones D to L.

Step 4: The estimates of annual growth in volume obtained in the previous step were multiplied by the ratios given by Smith (1976) to obtain the weight of wood plus bark for merchantable bolewood. Values for coastal and interior forests were summed for each species group.

Step 5: Besides the merchantable bolewood, carbon is also stored in the other nonmerchantable materials. One method of estimating the total biomass in the aboveground components is to multiply the weight of bolewood by an expansion factor to take into account the contribution of the other components. An implicit assumption for this method is that the allocation of new growth in a tree is proportional to the weight of each component.

According to Smith (1976), the nonmerchantable materials and small trees add another 2.1 to 2.3 times biomass to the bolewood alone. Independent data sources for estimating this expansion factor were the inventory reports by Bonnor (1985) and Forestry

Canada (1988). These data sources indicated that for non-reserved, productive, stocked, mature/ overmature forests in B.C.,

if average total above ground biomass is 232.89 ton/ha;

and average volume is 255.74 m^3/ha;

and average density of wood plus bark is taken to be 0.4; then

the expansion factor f = 232.89 / (255.74 x 0.4)

= 2.3.

This estimate is comparable to that presented by Smith (1976). Hence, an expansion factor of 2.3 was used for the mature/overmature forests in B.C.

For immature stands, the expansion factor may be higher than 2.3, since a higher percentage of the biomass is in nonmerchantable components and in submerchantable trees. Bonnor (1985) estimated that the average biomass of immature forests in B.C. is about 140 ton/ha. From the area of immature forests and the merchantable volume in these forests given in Canada's Forest Inventory (Bonnor 1982) an average volume of 96 m^3/ha was derived for immature forests in British Columbia. Taking the latter average and the same density value of 0.4, the expansion factor for immature forests in B.C. is estimated to be 3.6.

Allocation of carbon within a forest changes as the stand develops. Initially all biomass accumulated annually is unmerchantable. Later on, as full canopy closure is achieved, an

increasing proportion of new biomass is allocated to the stem instead of to leaves, twigs and branches. Thus, there is no single expansion factor applicable to all stages of stand development. The most accurate way to expand annual stem biomass increment to total above-ground annual increment is to actually sample annual increment of each component over a long period of time. It is impractical to do that for long-lived forest ecosystems. Therefore, a more common approach is to examine the ratio of total to merchantable forest biomass at given ages (rather than the ratio of total to merchantable annual increment). Some examples of total to merchantable biomass ratios (T/M ratios), derived from the literature, are listed below.

Type of stand	Stand age, yr	T/M ratio	Source
Softwood stands, Pacific Northwest and Alaska	variable	1.32	Johnson & Sharpe '83
Hardwood stands, PNW & Alaska	variable	2.04	Johnson & Sharpe '83
Rocky Mountain softwoods	variable	1.31	Johnson & Sharpe '83
Rocky Mountain hardwoods	variable	1.32	Johnson & Sharpe '83
All forest types in Puget Sound region, Washington	variable	1.97	Johnson & Sharpe '83
All forest types in central Washington	variable	2.27	Johnson & Sharpe '83

All forest types in eastern Washington	variable	2.10	Johnson & Sharpe '83
Amabilis fir stand in Puget Sound, Washington	180	1.5-3.3	Grier et al. '81
Western hemlock-Sitka spruce in southeast Alaska	110	1.3-1.4	Alaback '89

The expansion factors above need to be interpreted with caution because some of them refer only to above-ground biomass and others include one or more of standing dead trees, fallen logs, litter and humus, and roots. Obviously, the expansion factor will be strongly influenced by which of these components is included. For example, in a 180-year-old amabilis fir stand in the Puget Sound region, Grier et al. (1981) calculated a T/M ratio of 1.5 when only above-ground biomass was included but 3.3 when standing dead trees, fallen logs, forest floor detritus and roots were included.

Some examples of expansion factors based on increment of biomass components for a certain time interval, instead of accumulated biomass at a certain age, are described below.

Barclay et al. (1986) documented 9-year increment in a 34-year-old Douglas fir plantation at Shawnigan Lake, British Columbia. Using production for the 9-year interval the following T/M rations can be calculated:

	9-year production (t/ha)		
Stand treatment	stem	total above-ground	T/M ratio
unthinned, unfertilized	38.211	57.871	1.51
unthinned, heavily fertilized	53.557	83.791	1.56
thinned, unfertilized	30.744	49.646	1.61
thinned, heavily fertilized	48.257	77.561	1.61

Approximate biomass values, read from the graph in Figure 1 of Comeau (in prep. B), provide an estimate of the following T/M ratios for simulated development of above-ground and stem biomass for a lodgepole pine stand on a medium site in the British Columbia interior.

	10-year biomass increment* (mg/ha)		
Age interval, yr	stem	total above-ground	T/M ratio
20 - 30	35	43	1.2
40 - 50	40	40	1.0
60 - 70	11	11	1.0

* Approximate values because read from graph

Biomass yield tables prepared by Bella and DeFranceschi (1980) for aspen stands, 6 to 40 years old, in Alberta provide 2-year increments which can be used to estimate T/M ratios for that species. For the examples below, it was assumed that all stem biomass is merchantable so that some young age classes could be used in the example.

Good Site Aspen, Alberta

	2-year biomass increment (kg/ha)		
Age interval, yr	stem	total above-ground	T/M ratio
6 - 8	3988	6968	1.7
10 - 12	7522	11631	1.5
20 - 22	9081	12738	1.4
30 - 32	5766	7635	1.3
38 - 40	2726	3313	1.2

Poor Site Aspen, Alberta

Age interval, yr	2-year biomass increment (kg/ha) stem	total above-ground	T/M ratio
6 - 8	1048	2328	2.2
10 - 12	2790	4748	1.7
20 - 22	4153	6142	1.5
30 - 32	3110	4281	1.4
38 - 40	1856	2369	1.3

From the examples above it is evident that there is a broad range of possible expansion factors from which to choose when one wishes to convert merchantable stem inventory data to total above- g
round biomass.

APPENDIX IV

DETAILED COMPARISON OF INVENTORY

#	GROUP SECTOR	SUB-SECTOR	FUEL TYPE	THIS INVENTORY EMPR DATA 1988 EMISSIONS (kt CO2) ACTUAL	THIS INVENTORY EMPR DATA 2005 EMISSIONS (kt CO2) FORECAST	PARTIAL INVENTORY EMR DATA 1988 EMISSIONS (KT CO2) ESTIMATED	PARTIAL INVENTORY EMR DATA 2005 EMISSIONS (KT CO2) ESTIMATED	ENVIRONMENT CANADA DATA 1987 EMISSIONS (kt CO2) ESTIMATED
1.00	PROCESS SOURCES							
1.10	LIME KILNS			129.04	243.57			
1.20	CEMENT LIME KILNS			722.64	975.69			572.97
1.30	PULP&PAPER LIME KILNS			1638.10	1842.21			
1.40	METHANOL/AMMONIA			46.19	66.89			242.73
1.50	MISC. CHEM. IND.			17.50	25.34			
1.60	ALUMINUM SMELTING			650.00	650.00			
1.70	CO BOILERS (PETROLEUM REF.)			35.00	22.25			
1.80	CO2 FROM NATURAL GAS			0.54	0.67			
		SUM_1		3239.01	3826.62			815.70
2.00	STATIONARY FUEL COMBUSTION							
	GAS UTILITIES							
2.10			N.G.	2410.47	2973.84			
		SUM_2.1		2410.47	2973.84			1428.99
2.20	POWER GENERATION							
			N.G.	224.55	1609.98			
			DFO	178.14	30.68			
			HFO	75.83	109.63			
			PULP LIQ.	425.22	614.75			
			COAL		3274.02			
			HOG	228.93	410.61			
		SUM_2.2		1132.68	6049.67			425.98
2.30	RESIDENTIAL/AGRICULTURAL							
			N.G.	3566.03	4582.58	2976.33	4235.22	
			C&C	0.90	1.26	0.90	0.90	
			HFO		17.17	2.86	2.86	
			LFO	854.66	1156.67	822.49	515.43	
			LPG	96.20	262.76	225.00	376.39	
			DFO	113.10	458.21	275.69	301.85	
			RENEW.		623.57			
			KEROSENE			108.24	56.83	
			FARM GASOLINE					
		SUM_2.3		4630.89	7102.23	4411.51	5489.47	3555.57

#	GROUP	SECTOR	SUB-SECTOR	FUEL TYPE	THIS INVENTORY EMPR DATA EMISSIONS (kt CO2) 1988 ACTUAL	2005 FORECAST	PARTIAL INVENTORY EMR DATA EMISSIONS (KT CO2) 1988 ESTIMATED	2005 ESTIMATED	ENVIRONMENT CANADA DATA EMISSIONS (kt CO2) 1987 ESTIMATED
2.40		COMMERCIAL/PUBLIC ADMIN							
				N.G.	1717.93	3183.00	2247.03	3129.84	
				HFO	77.98	332.66	163.11	224.64	
				LFO	406.49	277.09	454.74	537.36	
				DFO	347.09	338.04	381.02	691.35	
				LPG	198.72	372.87	187.30	405.12	
				KEROSENE			116.36	110.27	
				AVIATION GAS			100.59	131.11	
				AVIATION TURBO			213.23	279.11	
			SUM_2.4		2748.22	4503.65	3863.37	5508.79	2644.73
2.50		INDUSTRIAL							
2.5.1			PULP&PAPER						
				N.G.	1168.47	1577.84			
				C&C	22.50	298.80			
				HFO	1568.87	1415.06			
				LPG	21.77	11.94			
				DFO	33.22	24.74			
				HOG	3702.00	4960.71			
				PULP LIQ.	14250.40	14349.19			
				OTHER					
			SUM_2.5.1		20767.23	22638.27			
2.5.2			WOOD PROD.						
				N.G.	691.05	482.69			
				HFO	6.44	3.22			
				LFO	9.50	5.92			
				LPG	52.67	17.41			
				DFO	690.64	218.64			
				HOG	1830.63	2673.68			
			SUM_2.5.2		3280.93	3401.57			
2.5.3			PRIMARY METALS						
				N.G.	106.32	229.52			
				HFO	2.86	9.23			
				LFO	4.39	9.65			
				DFO	7.07	15.06			
				LPG	0.70	0.91			
			SUM_2.5.3		121.33	264.37			

# GROUP SECTOR	SUB-SECTOR	FUEL TYPE	THIS INVENTORY EMPR DATA EMISSIONS (kt CO2) 1988 ACTUAL	THIS INVENTORY EMPR DATA EMISSIONS (kt CO2) 2005 FORECAST	PARTIAL INVENTORY EMR DATA EMISSIONS (KT CO2) 1988 ESTIMATED	PARTIAL INVENTORY EMR DATA EMISSIONS (KT CO2) 2005 ESTIMATED	ENVIRONMENT CANADA DATA EMISSIONS (kt CO2) 1987 ESTIMATED
2.5.4	CHEM. IND.						
		N.G.	214.12	264.30			
		HFO	43.64	22.89			
		LFO	2.92	5.12			
		DFO		2.83			
		ELEC					
		SUM_2.5.4	260.68	295.14			
2.5.5	NON-MET. MINERALS						
		N.G.	135.13	57.33			
		C&C	85.50	990.00			
		HFO		86.42			
		LFO		7.09			
		DFO	6.36	119.61			
		LPG	0.70	5.48			
		ELEC					
		SUM_2.5.5	227.69	1265.93			
2.5.6	PETROLEUM REF.						
		DFO	11.31	48.49			
		HFO	17.89	8.01			
		LFO	0.71	2.54			
		MOTOR GAS	0.68	20.39			
		PETR. COKE	179.40	70.15			
		STILL GAS	1032.24	273.17			
		N.G.	62.10	284.52			
		ELEC.					
		SUM_2.5.6	1304.32	707.29			
2.5.7	OTHER MFG.						
		N.G.	724.83	695.77			
		C&C	228.60	0.81			
		HFO	12.16	26.97			
		LFO	16.82	11.62			
		DFO	50.90	22.41			
		LPG	18.26	7.93			
		ELEC.					
		SUM_2.5.7	1051.56	765.52			

#	GROUP SECTOR	SUB-SECTOR	FUEL TYPE	THIS INVENTORY EMPR DATA: EMISSIONS (kt CO2) 1988 ACTUAL	THIS INVENTORY EMPR DATA: EMISSIONS (kt CO2) 2005 FORECAST	PARTIAL INVENTORY EMR DATA: EMISSIONS (KT CO2) 1988 ESTIMATED	PARTIAL INVENTORY EMR DATA: EMISSIONS (KT CO2) 2005 ESTIMATED	ENVIRONMENT CANADA DATA EMISSIONS (kt CO2) 1987 ESTIMATED
2.5.8		MINING						
			N.G.	341.80	100.20			
			C&C	360.90	755.46			
			HFO		345.25			
			LFO	0.73	29.90			
			DFO	732.35	1976.70			
			LPG	25.98	35.74			
			ELEC.					
			SELF GEN.					
			SUM_2.5.8	1461.76	3243.27			
2.5.9		OTHER IND.						
			N.G.	570.82	53.26	3080.66	4293.84	
			HFO		165.97	1693.35	1520.23	
			LFO	88.46	99.43	219.33	373.59	
			DFO	308.21	1337.10	1959.53	2458.60	
			KEROSENE			138.68	173.86	
			LPG			86.77	140.03	
			C&C			322.20	401.40	
			RENEW.			15426.34	19198.41	
			SUM_2.5.9	967.49	1655.76			
		SUM_2.5		29443.01	34237.11	22926.86	28559.95	20844.58
2.60		FUEL WOODSUM_2.6		667.29	667.24			325.79
		SUM_2		41032.56	55533.75	31201.74	39558.21	29226.64
3.00	MOBILE COMBUSTION							
3.10		ROAD VEHICLES						
			GASOLINE					5282.52
3.1.1			LDGV	5339.76	7197.85			2233.66
3.1.2			LDGT 1	735.54	991.83			
3.1.3			LDGT 2	1844.30	2486.71			579.73
3.1.4			HDVS	529.56	714.47			23.55
3.1.5			MOTORCYCLES	27.19	36.71			
			SUM_GASOLINE	8476.36	11427.57	8547.81	10118.14	8119.46

#	GROUP	SECTOR	SUB-SECTOR	FUEL TYPE	THIS INVENTORY EMPR DATA EMISSIONS (kt CO2) 1988 ACTUAL	THIS INVENTORY EMPR DATA EMISSIONS (kt CO2) 2005 FORECAST	PARTIAL INVENTORY EMR DATA EMISSIONS (KT CO2) 1988 ESTIMATED	PARTIAL INVENTORY EMR DATA EMISSIONS (KT CO2) 2005 ESTIMATED	ENVIRONMENT CANADA DATA EMISSIONS (kt CO2) 1987 ESTIMATED
			DIESEL						
3.2.6				LDDV	63.76	85.96			306.64
3.2.7				LDDT	60.72	81.86			2325.17
3.2.8				HDDV	2287.39	3342.08			2753.61
			SUM_DIESEL		2411.87	3509.90	2797.20	3733.85	5385.42
			N.G.		41.73	267.43	48.19	193.75	718.02
			LPG		302.19	283.70			236.31
			SUM_3.1		11232.15	15488.60	11393.20	14045.74	14459.21
3.20		RAILROADS							
				DFO	1588.97	1764.78	836.97	1261.11	
			SUM_3.2		1588.97	1764.78	836.97	1261.11	784.84
3.30		MARINE							
				HFO	1126.04	847.25	696.80	837.73	
				DFO	941.59	1569.18	953.61	1287.97	
				N.G.		0.99			
			SUM_3.3		2067.63	2417.42	1650.41	2125.71	860.22
3.40		AIR							
				AV. GAS	81.16	86.64	17.34	21.50	
				AV. TURBO	2084.11	2524.17	1944.56	2428.40	
			SUM_3.4		2165.28	2610.81	1961.90	2449.90	1904.19
3.50		OFF-ROAD	SUM_3.5		358.05	482.66			234.53
			SUM_3		17412.08	22764.27	15842.48	19882.46	18243.00
4.00	SOLID	WASTE DISPOSAL							
4.10		MUNICIPAL			243.38	450.70			35.29
4.20		LANDFILL GAS			310.62	193.72			
4.30		INDUSTRIAL&INSTITUTIONAL			14.24	17.84			52.29
4.40		WOOD WASTE		HOG	8828.09	6621.07			5531.18
			SUM_4		9396.33	7283.33			5618.76

#	GROUP SECTOR	SUB-SECTOR	FUEL TYPE	THIS INVENTORY EMPR DATA EMISSIONS (kt CO2) 1988 ACTUAL	THIS INVENTORY EMPR DATA EMISSIONS (kt CO2) 2005 FORECAST	PARTIAL INVENTORY EMR DATA EMISSIONS (KT CO2) 1988 ESTIMATED	PARTIAL INVENTORY EMR DATA EMISSIONS (KT CO2) 2005 ESTIMATED	ENVIRONMENT CANADA DATA EMISSIONS (kt CO2) 1987 ESTIMATED
5.00	OPEN BURNING			0.00	0.00			0.00
5.10		PRESCRIBED BURNING		13300.00	9300.00			7161.23
5.20		WILD FIRE		350.00	4300.00			0.00
		SUM_5		13300.00	9300.00			7161.23
GRAND SUM OF ALL SECTIONS				84379.99	98707.96	47044.22	59440.67	61064.32

APPENDIX V

DETAILED FORECASTING METHODOLOGY FOR CO_2 EMISSION SOURCES

2. Process Sources

(a) Cement Production

One of the companies producing cement clinker in B.C supplied an estimate of their 2005 output, while another company supplied 1990 output estimates. A growth of 29% for the 1990/2005 period, supplied by Environment Canada (Sheffield, 1990) was used. This was in line with the industry supplied value. There was no GDP forecast available for B.C. The growth was based on projected GDP ratios for 1990 and 2005.

(b) Lime Kilns

The forecast of lime kiln CO_2 emissions was 89% based on estimates provided by the companies operating lime kilns in B.C.

(c) Lime Kilns in the Pulp and Paper Industry

The CO_2 emissions from lime kilns in the pulp and paper industry were forecast to increase by 12% between 1988 and 2005. This growth is based on the EMPR forecast of pulp production growth in the pulp and paper industry (EMPR, 1986).

(d) Methanol/Ammonia Production

Increased emissions of CO_2 from production of methanol/ammonia in B.C. were based on an extrapolation of historical GDP growths in the chemical industry for B.C. (B.C. Central Statistics Bureau, 1989). CO_2 emissions were forecast to grow by 45% between 1988 and 2005.

(e) Other Chemical Processing Industries

Emissions of CO_2 from the lone chemical process were forecast to increase by 45% based on an extrapolation of historical estimates for the chemical processing industry.

(f) Aluminum Smelting

Alcan did not expect any change in CO_2 emissions from their Soderberg pots.

(g) CO Boilers

CO_2 emissions from CO boilers were forecast to grow (decline) at the same rate as petroleum industry energy consumption. This results in a decline in CO_2 emissions of 36%.

(h) CO_2 Stripped from Natural Gas

Emissions of CO_2 stripped from natural gas were forecast to increase proportional to the amount of gas consumed. Environment Canada's (Sheffield, 1980) growth projection of 23% was assumed.

3. Stationary Combustion Sources

The forecasts of all stationary combustion source energy requirements, except for power generation and fuel wood, were supplied by EMPR (1986). These forecasts were based on 1984 statistics. Consequently, the forecasts of some sectors will appear rather high or low. The overall growth is reasonable.

(a) Gas Utilities Sector

Increased fuel consumption by gas utilities for transmission and other uses was forecast using Environment Canada's (Sheffield, 1990) growth projection of 23% for gas utilities.

(b) Power Generation Sector

B.C. Hydro provided an estimate of the thermal power generating projects most likely to go ahead. Fuel requirements were estimated based on these project outputs. The assumptions included cancelling the Hat Creek coal generating project, replacing the 600 MW East Kootenay project with a 300 MW coal generating scheme and two hog fuel cogeneration projects. Fording Coal generating project and Westcoast gas cogeneration projects were assumed to be in place in 2005. This last assumption had a minor effect on forecast CO_2 emissions. The overall growth in thermal electricity production between 1988 and 2005 was projected to be 448%. This is because so little thermal generation took place in 1988.

(c) Residential and Agricultural Sector

The 2005 forecast energy requirement for the residential and agricultural sector was taken from the EMPR report (EMPR, 1986). The EMPR forecast the mainland and Vancouver Island separately. For both regions, energy requirements were estimated by relating energy demand to energy prices, real disposable income and heating degree days. Individual fuel demands were derived by applying market shares to total energy.

Market shares were only forecast for oil and electricity on the Island. Natural gas requirements were estimated on the expected level of electricity and oil displacement resulting from natural gas service to the Island. The overall growth between 1988 and 2005 in energy consumption was projected at 46%.

(d) Commercial and Public Administration Sector

The EMPR forecast for 2005 energy requirements was used to forecast CO_2 emissions. In their report (EMPR, 1986), the complete forecasting methodology is outlined. Briefly, the commercial and public administration sector energy requirements were forecast for the mainland and Vancouver Island separately. In both cases, regional commercial energy requirements were related to projections of economic and demographic activity. Fuel shares were used to estimate individual requirements for the various fuels.

The overall growth between 1988 and 2005 was projected at 69%. The high value reflects changes from electricity to fossil fuel use.

(e) Industrial Sector

(i) General

The EMPR has provided a detailed discussion of methodology in their report (EMPR, 1986), which includes all the assumptions used for forecasting energy requirements in the industrial sector. Their approach was to forecast each subsector individually, using Gross Domestic Product, and adding information or constraints supplied by industry whenever possible.

(ii) Forestry

The forestry subsector includes pulp and paper as well as wood products. Logging is included in the "other industrial" subsector. The EMPR maintained the maximum allowable cut at a constant level throughout the forecast period. This constraint seems to be a reasonable balance between increased pulp and paper production and a call from environmentalists to reduce logging. Subject to this constraint, the supply of wood chips remained constant while lumber production increased by 8%. These assumptions have ramifications in the wood waste subsector which will be discussed in that section.

The overall growth in energy consumption between 1988 and 2005 was projected at 11%.

Another assumption in EMPR's 1986 forecast was that only two chemi-thermomechanical pulp (CTMP) mills would be in operation. These are high yield pulping processes which have higher electricity but lower thermal energy demands than Kraft mills. Furthermore, CTMP mills do not have recovery boilers which produce energy from spent pulping liquors. Since there are already several high yield processes in operation, and more

on the drawing board, future energy consumption patterns could change significantly.

The EMPR is working on an updated energy supply and requirements forecast which will take into account the new situation. Since the forestry subsector is such a large energy consumer, it will be important to improve the forecast of growth and changes in production technology, particularly for pulp and paper.

(iii) Primary Metals

The EMPR have included a new Alcan smelter at Vanderhoof, a new Cominco lead smelter, a ferro-silicon smelter complex and a copper smelter to be on line before 2005. Obviously, energy requirement projections will depend on whether or not these projects go ahead as well as their timing. Again, the updated version of EMPR's Energy Supply and Requirements Forecast might significantly differ in its energy consumption forecasts from what was available for this study.

Total energy requirements were projected to increase at 1.4% per annum to 1995 and then 3.7% per annum thereafter. The combustible energy consumption between 1988 and 2005 was projected to grow by 117%.

(iv) Chemicals

The chemical subsector's share of real provincial GDP was forecast to increase at an average annual rate of 2.4%. Combustible energy requirements were forecast to increase by 16% between 1988 and 2005.

(v) Non-Metallic Minerals

The cement industry dominates this subsector. Consequently, the forecast strongly reflects expectations in the domestic construction industry and exports to U.S. markets.

GDP for construction was forecast to increase at 4.1% per annum to 1995 and then 3.1% per annum thereafter. Exports to the U.S. were forecast to grow at 0.5% per annum.

It is important to note that two of the cement plants in B.C. plan to shift their consumption of fuel from natural gas to coal. This is reflected in the EMPR forecast. The forecast for 2005 energy consumption in this subsector was based on 1984 energy usage statistics. This resulted in a very high (304%) energy consumption estimate relative to 1988 energy statistics. The update of EMPR's energy supply and requirements forecast

will revise the forecast downwards. Regardless, this affects the total CO_2 emissions estimate by less than 1%.

(vi) Petroleum Refineries

The EMPR forecast allows for the possibility of at least one refinery closure. Because Alberta can supply most of the refined petroleum products (RPP) now produced in B.C. at substantial cost reductions, a reduction of the B.C. industry is expected. A reduction in combustible energy consumption (not refined petroluem production) of 42% was assumed between 1988 and 2005.

(vii) Other Manufacturing

GDP for this subsector was forecast to grow by 4% per annum to 1995 and then slow to 3.6% thereafter, according to the EMPR forecast (EMPR, 1986). The combustible energy consumption was forecast to grow by 81% between 1988 and 2005.

(viii) Mining

Metal mining was forecast to grow at an average rate of 2.3% per annum to 2005. Some increased production from new mines was expected to be largely offset by reduced output or depleted reserves at older mines. Metallurgical coal production was forecast to grow at an annual rate of 2%. An additional 2.1 million tonnes of anthracite coal production was included in EMPR's forecast. The combustible energy consumption was forecast to grow by 104% between 1988 and 2005.

(ix) Other Industrial

Diesel fuel requirements were forecast separately for the construction and logging industries. Annual diesel fuel requirements were forecast to grow at 3.6% and 0.9% for construction and logging, respectively, which equals the growth rate in GDP for these industries.

All other fuel requirements were forecast to grow at a combined industry growth rate. The combustible energy consumption was forecast to grow by 39% between 1988 and 2005.

(f) Fuel Wood

Fuel wood consumption on Vancouver Island is likely to decrease when natural gas becomes available. The natural gas pipeline will bring more convenient gas to some homes now relying largely or totally on

wood for space heating, leading to a gradual switch to natural gas heating. Forecasting a decrease in fuel wood consumption in B.C. may be overly optimistic, consequently, to be conservative, no changes in wood fuel consumption were assumed over the forecast period.

4. Mobile Combustion Sources

EMPR has forecast changes in transportation energy demand based on changes in economic, demographic and technology variables. Each sector was forecast individually. As with stationary combustion sources, the forecast in energy consumption was supplied by EMPR (1986) using 1984 as the base year, with the exception of the road sector.

(a) Road

The EMPR estimated transportation fuel demand by multiplying total distance travelled by fuel efficiency. The distance is affected by increased population, economic growth and lower real fuel prices. B.C. fleet fuel economies were estimated based on U.S. Department of Energy Corporate Average Fuel Efficiency Standards for Ford, General Motors and Chrysler. On this basis, EMPR forecast increases in gasoline and diesel consumption of 11% and 52% respectively for 1988 to 2005.

This motor gasoline forecast appeared too low because the number of vehicles per person is also increasing. Consequently, we used population to forecast motor gasoline demand in 2005. This approach assumes that increases in the per capita number of vehicles offsets improved fleet fuel economies and any potential reductions in average distance travelled per vehicle in the future. Population was forecast to grow by 35% according to the Ministry of Finance.

Diesel fuel consumption for heavy duty diesel vehicles was forecast to grow by 46% between 1988 and 2005 based on historical GDP growth in the transportation and storage section (B.C. Central Statistics Bureau, 1989). Other diesel vehicles were forecast to increase consumption according to population.

(b) Rail

The rail industry provided forecasts of energy requirements for 2005. Their individual estimates resulted in an overall increase in diesel fuel consumption of 11% between 1988 and 2005. While this may be high, it will have a very small impact on total CO_2 emissions.

(c) Marine

EMPR forecasts a decline in heavy oil and diesel prices in real terms over the period to 2005. Exports of coal, grain and lumber were expected to grow at an annual rate of 3.6%. Coastal lumber production

was expected to grow at 1.3% per year. Combustible energy consumption was forecast to grow by 17% between 1988 and 2005.

(d) Air

Aviation gasoline and turbo fuel prices were forecast to decline to 1996 and then increase marginally at 0.1% per year. Steady growth in consumer prices and income were forecast by EMPR. On this basis average air travel was expected to grow 4.6% per year. Combustible energy consumption was forecast to grow by 21% between 1988 and 2005.

(e) Off-Road Gas

Off-road fuel requirements were forecast to grow at 35% according to growth in population.

5. Solid Waste Disposal

(a) Municipal Solid Waste

Recent initiatives by the Ministry of Environment to curb waste disposal by recycling and by reducing waste generation rates, may reduce the need for municipal incineration in the short term. General opposition to incineration is also expected to be strong in the short term. Diminishing landfill capacity, however, is likely to force at least one more provincial municipal incinerator similar in size to the GVRD incinerator by the year 2005. The smaller incinerators now in operation would likely be phased out by 2005. These assumptions resulted in an 85% increase in solid waste incineration volumes by 2005.

(b) Industrial Solid Waste Incineration

A marginal increase in industrial incineration was forecast to keep pace with increased international air and marine traffic. The Vancouver International Airport waste incineration rate was forecast to increase at the same rate as the air sector energy requirements. A conservative estimate of 21% over the forecast period was used.

Similarly, international marine waste was expected to increase at 17% per year, the same rate as the marine energy requirement forecast.

(c) Landfills

Increases in total solid waste generation because of increased population was expected to be offset by decreases in per capita waste generation rates and recycling efforts. Annual landfilling rates between 1988 and 2005 were also forecast to decrease by the amount of increase in incineration. Total solid waste disposal rates were forecast to decrease by 22% between 1988 and 2005. Because of an increase

in incineration, landfilling rates were projected to decrease by 38% between 1988 and 2005.

(d) Wood Waste

Wood waste incineration was expected to decline because of increased use of wood waste in the pulp and paper and wood products industries, more efficient cutting and chipping technology at sawmills and increased use of hog fuel for power generation in the forestry sector.

A decline of 25% in wood waste incineration over the period 1988 to 2005 was assumed. This results in hog fuel quantities to remain approximately constant at 1988 levels.

6. Prescribed Burning

A 30% reduction in prescribed burning by 2005 was projected for CO_2 emissions based on an estimate provided by the B.C. Ministry of Forests (Spittlehouse, 1990).